BIOLOGY OF ANIMALS

Volume I

Ganguly • Sinha • Adhikari

New Central Book Agency

BIOLOGY OF ANIMALS

VOLUME I

Text Book for Degree Students

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India

ABOUT THE COVER	Colony of *Hydra vulgaris* in laboratory culture. Photo by Dr. S. Bhattacharya, U. Mallick and Miss R. Palit of the Zoology Dept. Presidency College, Calcutta.
PUBLISHER	Jogendranath Sen, B. Sc. New Central Book Agency 8/1 Chintamoni Das Lane Calcutta 700 009
PRINTER	B. N. Das Books & Allied (P) Ltd. (Printing Section) 8/1 Chintamoni Das Lane Calcutta 700 009
PRICE	Rupees 45·00 (in India)

TO

OUR TEACHERS

WHO

TAUGHT US ZOOLOGY

Banku

Arup

Simananda

Contents

Foreword

Sivatosh Mookerjee DEPARTMENT OF ZOOLOGY ● PRESIDENCY COLLEGE ● CALCUTTA 12

PROFESSOR & HEAD OF THE DEPARTMENT
DIRECTOR: NCERT BIOLOGY STUDY GROUP

The writing of a viable text-book is not as easy as it appears to be. Without being endowed with a natural sense of communication, clarity of exposition and certain degree of originality in organizing the material, the attempt to write a text would be a costly misadventure. The prospective writer must consciously control the osmotic gradient of fresh knowledge flowing into the pool of the existing one. The process of science is revealed in its unceasing progress; this means that the horizon of knowledge is continuously receding. The greatest obligation of a text-book writer is to remain alive to this fact and to minimize the gap by constant vigilance. Texts, written once cannot be perpetuated indefinitely. Texts are not intended to enslave the mind but to prepare it for more knowledgeable things hidden beyond the present contemplated boundaries. Its purpose is to arouse a sense of aptness for the subject concerned and to embolden curiosity for its material contents, in order to lead the way to the further progress. The purpose of a book lies in the mental preparedness for creating a new sense of dedication for the unknown.

To attempt now to write a text in Zoology for the Degree Course would be a matter of great adventure because modern Zoology has undergone a radical ecdysis and has emerged out into a new conceptual entity, both in contents and implications. Zoology is no longer a mere plethora of disjointed morphological descriptions. It is now a field of coherently integrated and biochemically analysable entity. Biological diversities have become resolved into a common theme of endless activity of the wonder molecule of DNA. Throughout the new vista of Zoology, causal interpretations of functional dynamism, adaptiveness in time, exploration of new ecological niches, biometry of forms have firmly been established.

The writers of the present volumes were my close collaborators in research. The image of modern biology is clearly inscribed in their minds. It is heartening to see that they have been able to assemble the main ingredients of the science of Zoology in a most coherent way and organised their material into a principle oriented discourse. Our syllabi, in most of the Universities, even to-day suffer from serious limitations. Often the contemporary outlook of Biology is not fully reflected in our curricula. However, within the available framework of the present-day curricula, the authors have done their best to convey the message of modern Zoology. I have no doubt that the present volumes will generate impact on the modernization of the subject which we have cherished so much and for so long.

Sivatosh Mookerjee

We have decided to write a book on Zoology which would reflect the contemporary outlook of the subject and at the same time, would cover the syllabi of most Indian Universities. Our prime objective would be to see that the book helps the student to learn the subject. We expect the student to be a true literate in Zoology. They should be in a position to use their knowledge and training in their daily life and vocation. It is hoped that instead of mere cramming of the 'product' parts of the subject, the students will learn the 'process' involved in it. Such training would develop in their mind a sense of love and appreciation about the subject.

The abovementioned paragraph was written before the writing of the manuscript. It speaks about our desired objectives. In order to attain it we have selected the most important theme of today's biology—*unity and diversity in living organisms*. As it is a book on Zoology, we have restricted ourselves only to the animals. The book begins with the idea of 'unity', the understanding of which can only help the reader to realise the guiding principles involved in the production and maintenance of the enormous array of 'diversity'. In the first volume, unity in the living world and non-chordate animals as the examples of diversity are included. The second volume has been devoted to the examples of chordates and different other biological principles.

To satisfy the requirements of the Universities, the part dealing with the examples of diversities has become unusually longer. It is hoped that the readers of this book would find that the underlying principles of Zoology are more vital than the descriptive legends of animals. While presenting the facts we have taken this into consideration that figures become integral part of the text. Two types of illustrations have been used—some are of more artistic value while the others are line drawings for the easy understanding of the students. As far as practicable, Indian examples have been described and the work of Indian scientists incorporated.

We have no hesitation to admit that in spite of our best effort, we have not been able to reach our desired objectives. Repeatedly we found that it is impossible to reflect the 'contemporary outlook of the subject' in the frame work set for "the requirements of syllabi of our universities".

It is rather an unfortunate truth that even after the criticism of Kothari Commission, most Universities of our country have failed to implement a syllabus which would reflect the contemporary outlook of knowledge. We sincerely appeal to the teachers to come forward to convince their Universities to make the curriculum of Zoology not only modern but also more useful and meaningful. An ideal curriculum includes both the syllabus and the methods of its implementation. Both are interdependent and to make the curriculum successful it is necessary to consider both very carefully. It is needless to emphasize that the

present method of teaching requires a change. A student of Zoology must learn the subject as a scientist. It is necessary to see that teaching of Zoology creates in the mind of the student a sense of enthusiasm and inquisitiveness. How can this goal be achieved? Which one will be best effective—enquiry approach or classical lecture-type method or both. The final answer can come only from the teachers who are involved in it. The authors of this book only want to assure that if something in this direction is done they will be glad to recast the entire content.

We are fortunate that in the preparation of this book we enjoyed the help and counsel of a large number of very competent persons. The acknowledgement of their names does not necessarily mean that they have approved everything in our final manuscript. We are grateful to them for their keen interest, untiring labour and critical but friendly co-operation, which have definitely put this book into a presentable shape.

We are specially thankful to Professor Sivatosh Mookerjee, F.N.I., Head of the Department of Zoology, Presidency College, Calcutta, for the genuine interest that he has kindly shown towards this book. Professor Mookerjee, who among a few others, was primarily responsible for bringing in the era of modern biology in the country, helped us many a times with his creative ingenuity during the various phases of gestation of the book. He was too kind to extend all the facilities of his laboratory to us. With deep respect we acknowledge the apt and excellent foreword that he has written for this book.

We shall be glad to acknowledge all comments, suggestions and corrections from the learned teachers and enthusiastic students. As this is the only way to improve the book further, we will give due honour to them.

Last but not the least, we appreciate the courage of Sri J. N. Sen of New Central Book Agency for entrusting upon a comparatively younger group of people to write the book on Zoology in their series of Biological Sciences. We are happy in being able to fulfil the responsibility assigned to us and that too, in much ahead of the stipulated time.

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PREFACE TO THE SECOND EDITION

In the first edition of this book we wrote that our goal is to write a viable text-book on Zoology that would reflect the contemporary outlook of the subject and would cover the syllabi of most Indian Universities. That the objective has been fulfilled is amply clear from the favourable reception of the book by both teachers and students. With much pleasure we are presenting a Second Edition of the book.

Our colleagues in the line have inspired us by sending valuable suggestions and criticism for the betterment of the book. Those suggestions have been incorporated in the text as far as practicable. Even a casual look into the book will reveal that a major part of the contents of the first edition has been thoroughly recasted to bring it in tune with the present day information.

We feel that there is further scope of improvement of the book and as such we would appreciate receiving suggestions, comments and criticism from our learned colleagues all over the country.

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PREFACE TO THE THIRD EDITION

With much pleasure we are presenting the third edition of Biology of Animals Vol. I. The book has received cordial acceptance both from the teachers and students of this subcontinent. Our chief aim was and it stands even today to write a 'viable' text book on Zoology. To make the book viable we have tried to marshall the present-day information as far as practicable so as to incorporate them. This, indeed, a tremendous task but failure on our part to do so will tentamount to stepping out of our earlier promise.

We are looking forward to receive help in the form of constructive criticism both from teachers and students.

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Acknowledgements

The authors acknowledge with gratitude the help rendered by the following persons during the preparation of this book.

Late Harendranath Ray (Presidency College, Calcutta) Sivatosh Mookerjee (Jawharlal Nehru University, New Delhi) Kumudshankar Das (Surendranath College, Calcutta) Sambhunath Roychoudhuri (Presidency College, Calcutta) Ajit Banerjee (Presidency College, Calcutta) Dhrubajyoti Lahiry (N.C.E.R.T., New Delhi) Amitavashankar Bhadury (Bangabasi College, Calcutta) Bijnananda Roy (Bangabasi College, Calcutta) Jaganmoy Mitra (N.C.E.R.T., New Delhi) Satyabrata Bhattacharya (Darjeeling Govt. College) Ashim Chakravarty (North Bengal University) Ajit Aditya (Hooghly Mohsin College) Subir Ganguly (Barisha Vivekananda College) Sujit Dasgupta (Hooghly Mohsin College) Somes Sanyal (Medical faculty, Rotterdam University, Rotterdam, The Nedarlands) Himangshu Banerjee (Presidency College, Calcutta) Sudhangshu Das (Sri Chaitanya College, Habra) Sudhangshu Ghosal (University of Burdwan) Amiya Kr. Chatterjee (Jhargram Raj College) Keshab Mookerjee (Ashutosh College, Calcutta) Arunava Dutta (City College—day, Calcutta) Nurjahan Adhikari (Bethune College, Calcntta) Sunil Datta (Kalyani Bidhanchandra Agricultural University) Sailesh Guha (Serampore College) Hrishikesh Chatterjee (Barisha Vivekananda College) Samar Chatterjee (Jawharlal Nehru University, New Delhi) Amal Bhattacharya (Jhargram Raj College) Dipak Chatterjee (CIBA Research Centre, Bombay) Nitis Ranjan Das (Serampore College) Runu Bhattacharya (Darjeeling Govt. College,) Utpal Mallik (N.C.E.R.T., New Delhi) Debaprasad Chakrabarty (Taki Govt. College) Robin Guin (Presidency College, Calcutta) Samar Ghosh (Sri Chaitanya College, Habra) Sushanta Ghosh (Surendranath College, Calcutta) Madan Dutta (Zoological Survey of India) Bhabani Shankar Joarder (Ashutosh College, Calcutta) Nirmal Sarkar (Presidency College, Calcutta).

The authors wish to express their heartiest thanks to Shri Gosaidas Paul, Shri Biren Das and Shri Sunil Paul for drawing the diagrams and illustrations used in the present text. The authors also appreciate the assistance rendered by the staff of Messrs. New Central Book Agency and Books and Allied (Printing Section) of Calcutta in the preparation

BIOLOGY OF ANIMALS

VOLUME I

Life is a peculiar state of existence, so much different from non-life. Only the plants and animals can experience such a state, leaving aside still smaller forms known as viruses. There are bewildering forms of plants and animals probably with all imaginable differences in size and shape. This system of biological diversity can conveniently be harnessed into another pattern of unity—a unity in the ultimate similar chemical make-up of all forms constituted by protoplasm. Protoplasm is a peculiar amalgam of different chemical recipes, fortified by a system of self-maintaining equilibrium.

Unity and diversity are the two facets of the bundle of life. Understanding of the mechanism involved in the form and function of life constitutes the subject matter of modern life science. Modern biology thus begs the assistance of such disciplines like physics, chemistry, mathematics, to give their hands for the ultimate solution of the life process.

Zoology, the subject matter of this book, is that branch of biology, which deals with the science of animal life.

PART ONE

LIFE WITHIN ANIMAL

Biology is the science of life. What is life ? What are the constituents of living body ? How these constituents work ? Answers to these questions will be sought in this part of the book.

CHAPTER 1

Properties of Life

It is difficult to define life, but almost everyone knows where life is. Life is expressed in certain activities which are regarded as the properties of life. What are these properties which make the living beings unique ?

No one feels any difficulty in distinguishing living forms from non-livings. Numerous animals, from amoeba to man and innumerable plants, from alga to banyan tree, all are living, while rivers, rocks and clouds are non-living (Fig. 1.1). What are the characteristics of living body? It may be said briefly that the characteristics are—(I) *complex organisation*, (II) *maintenance of steady state*, (III) *growth*, (IV) *reproduction*, (V) *adaptation* and (VI) *evolution*.

Fig. 1.1. Both living and non-living exist together on the earth. How can we identify a fish, a horse, a bird and a tree as living ?

I. **COMPLEX ORGANISATION.** Man has built up many complicated machines which work with great precision. But the working of his own body machine has exceeded all of them in complexity and precision (Fig. 1.2). With the aid of his tools, man has learnt about the organisation of living body. It is known that all living bodies are made up of units called CELLS. Some possess only one cell while others have many. In the multicellular forms, the cells with similar forms and functions are grouped as TISSUES. The tissues make up an ORGAN and several organs participate to form a SYSTEM which performs some vital function. Combination of few systems constitutes a multicellular organism. Up to the beginning of this century man was busy in

Fig. 1.2. Living body has more complicated organisation than any man made machine.

unravelling the different systems in the different animals. But with the advent of different techniques in this century, man is continuing his probe to understand the organisation at subcellular level. Considerable amount of facts is known about the atoms and molecules present there and the mode of their action, their properties at the functional level.

II. **MAINTENANCE OF STEADY STATE.** All activities like the running of an automobile, burning of a candle, jumping of a frog or the flying of a bird involves expense of energy. Non-living bodies like a battery, after certain period of work lose all its energy. It has no way to maintain its steady state. A living body, too, loses energy during work, but is able to carry on complicated chemical activities to maintain a steady state. It must be remembered that this equilibrium is a dynamic steady state and not a static one. Living system procures energy-yielding substances from the environment in the form of food (Fig. 1.3) and converts them

Fig. 1.3. Food is necessary for sustenance.

into its own body substance. This process is called *nutrition*. These body substances are burnt by oxygen which is taken in from the environment, resulting in the release of energy and production of carbon-dioxide and water. The energy is utilised by the body during its activities while the carbon-dioxide and water are given out. The entire process of energy release and the gaseous exchange is called *respiration* (Fig. 1.4). Thus nutrition works for the building up of body substances (*anabolism*) and respiration is involved in its breakdown (*katabolism*). The anabolism and katabolism are together called *metabolism*. When anabolism exceeds katabolism, new materials are added to the body. Such a phenomenon of replenishment is not seen in non-living objects like rocks, which always retain the same old atoms and cannot replenish the loss.

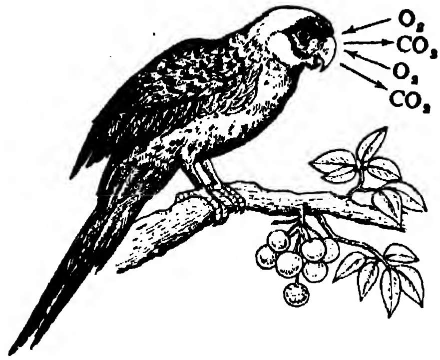


Fig. 1.4. Living body takes in oxygen and gives out carbon-dioxide. The ultimate result is release of energy which is used during various work that are done by the living body.

Another phenomenon which helps in the maintenance of steady state is the *response to stimuli*. Any change in the external environment or any alarm from the internal parts, is at once detected and attended to (Fig. 1.5). For example,

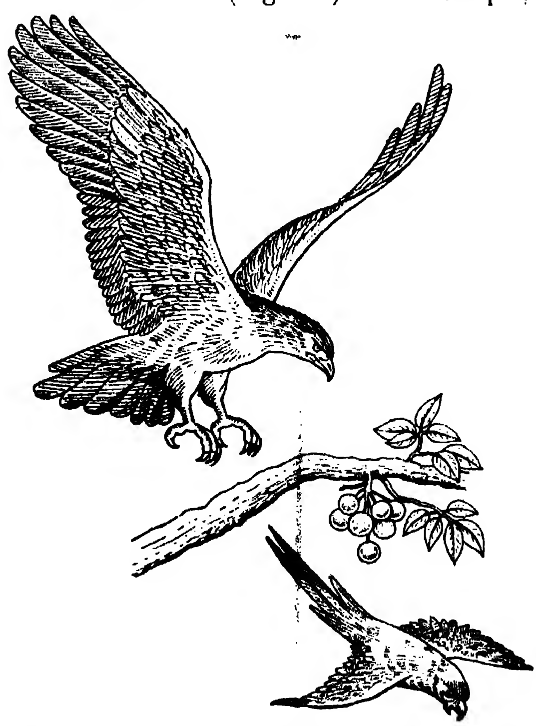


Fig. 1.5. Showing an example of response to stimuli. In the hunting bird the stimulus is positive and to the prey it is negative.

sight of a snake on the road immediately alarms us and we speed up to reach a safe place. Similarly, stimuli may come as sound, odour, touch, pain, heat and cold; we always react to them. The process of metabolism and the power of responsiveness are thus two unique features in the living system, which help in the maintenance of equilibrium at dynamic level.

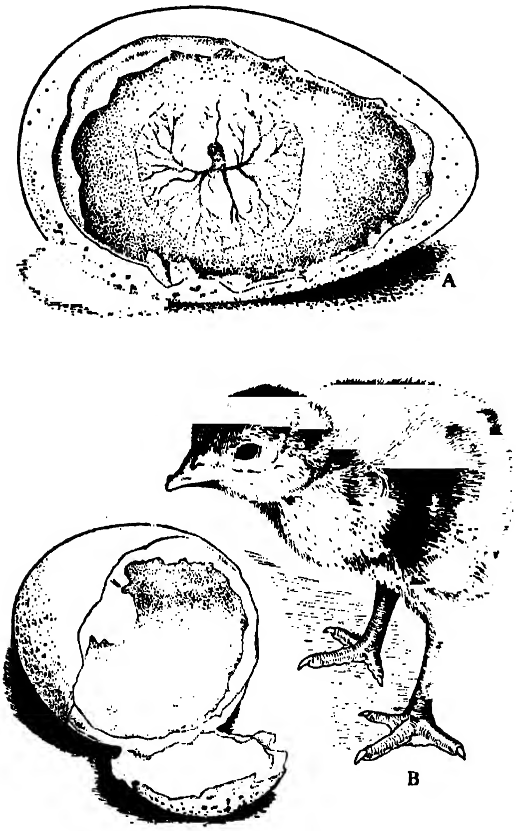


Fig. 1.6. Showing an embryo within the egg (A) and just hatched chick (B). The embryo in course of its development has used up the yellow yolk and converted them into its own body material to become a chick. Such growth is not seen in non-living.

III. **GROWTH.** When anabolism exceeds katabolism, the individual grows. Some non-living crystals in solution may grow in bulk, but here the growth is by the addition of identical materials available as such. Whereas in living body growth takes place by the conversion of materials which are dissimilar to its body (Fig. 1.6).

IV. **REPRODUCTION.** After certain period of growth, all living beings tend to multiply. This multiplication is known as reproduction which may be either by

Fig. 1.7. Reproduction leads to multiplication of individuals in the species.

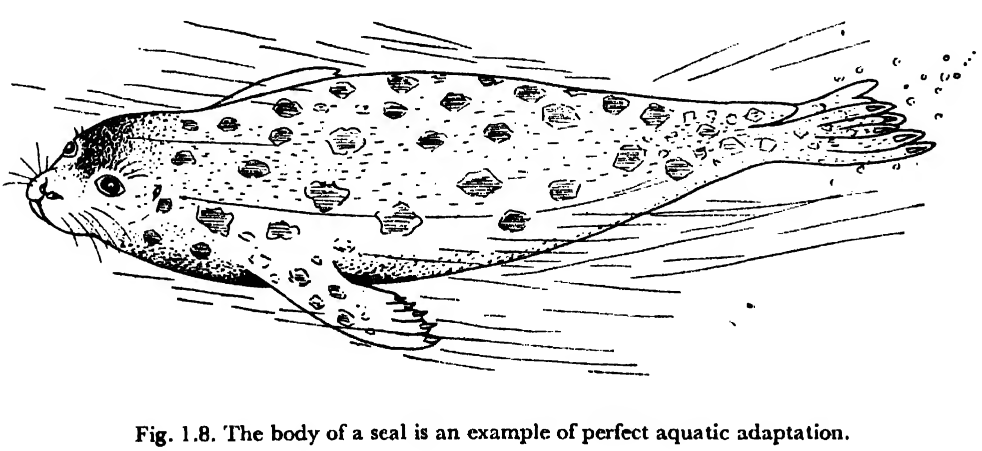


Fig. 1.8. The body of a seal is an example of perfect aquatic adaptation.

participation of entirely one individual (asexual) or by the contribution of the two (sexual). Such multiplication in number by self-duplication is not seen in the non-living world (Fig. 1.7).

V. **ADAPTATION.** All living forms have the wonderful ability to adapt themselves to their particular environment. Such adaptive behaviour permits certain forms to flourish well and allows them to survive in the course of evolution. Land, air, water, whatever it may be, are invaded by some or other forms of life, that have perfectly adjusted to the environment through suitable changes in their organisation (Fig. 1.8).

VI. **EVOLUTION.** The living world, as we see it today, was not the same in the past. Many species of plants and animals that lived in distant past exist no longer and have now become extinct. At the same time many new forms have emerged. Life first originated as a very simple form. From that starting point it has marched through thousand million years and has reached the present level of complexity and diversity. It involved gradual changes and such changes occurred from generation to generation. It is known as *evolution*. The most remarkable feature in the evolution of living beings is that only those which could adapt themselves to continuous changes in the environment survived, while others which failed became extinct. Such production of variation to meet the ordeal of evolution is not seen in the inorganic world. Figure 1.9 shows few stages through which the horse passed before attaining the present form.

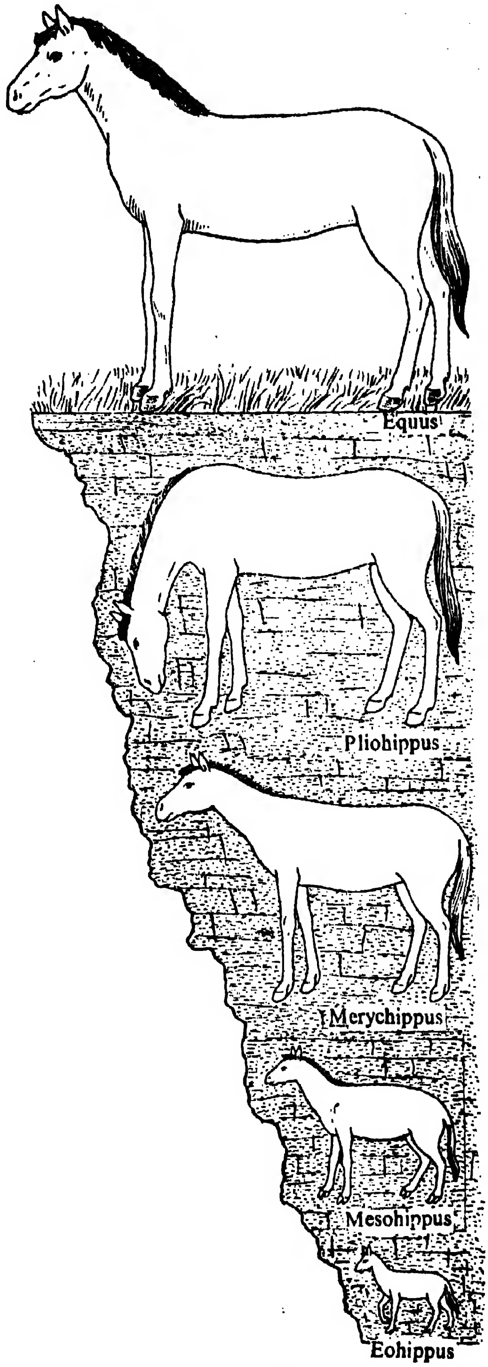


Fig. 1.9. Evolution of horse.

SUMMARY

All living forms exhibit certain characters which are regarded as features of life. These characteristics are—*complexity of organisation, maintenance of steady state, growth, reproduction, adaptation* and *evolution*.

CHAPTER 2

Constituents of Living Matter

The flame has no separate existence without the candle (Fig. 2.1). So is life. It

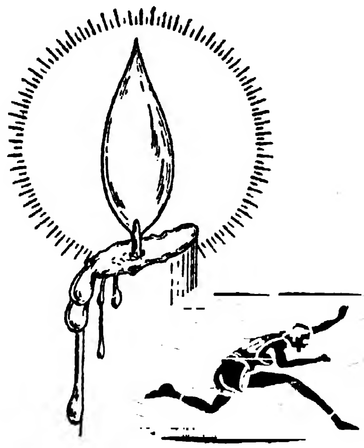


Fig. 2.1. Flame of a candle has no separate existence without the candle.

cannot exist without a body. Such a body having life is called living body. A candle is composed of different elements—carbon, hydrogen, oxygen, etc. What constitutes the living body?

The substance which forms the fabric of living matter is known as **protoplasm.** It has certain physical and chemical characteristics and in addition, certain other features—which are the properties of life. These properties, known as biological characteristics, have already been discussed in the preceding chapter. The physical characteristics of protoplasm are —it is soft, jelly-like, discontinuous substance which constantly transforms itself from a stage of 'sol' to 'gel' and *vice versa.* This internal change of state is due to its chemical nature and through this activity the protoplasm always releases energy. Chemically, protoplasm is a colloidal, water-dependent mixture of chemical substances. These substances mainly include four primary elements, carbon, hydrogen, nitrogen and oxygen, of which carbon plays the most important role. Because of its covalent nature, carbon sets the complex organisation of living matter and serves as "the very basis of life itself".

CHEMICAL ANALYSIS OF LIVING MATTER

Following elements are known to be present in the protoplasm—**carbon, nitrogen, hydrogen, oxygen, traces of chlorine, iron, calcium, magnesium, phosphorus, potassium, sodium** and **sulphur.** In addition, certain other elements, e g. copper, magnesium, fluorine, boron, silicon, aluminium, cobalt and zinc may be found in small quantities. These elements are organised into compounds having great complexity of molecular structure. Those compounds are of two categories—(I) *Inorganic* and (II) *Organic.*

I. **INORGANIC COMPOUNDS.** These are represented by (A) *Water* and (B) *Inorganic salts.*

A. **WATER.** This is most important for the living body. Major bulk of protoplasm is made up of water (66% in man; nearly 90% in jelly fish). It does the following

functions: (1) acts as solvent for other inorganic and organic substances, (2) serves as a medium of every chemical reaction that occurs within the living body, (3) remains as a liquid for considerable range of temperature and is an excellent

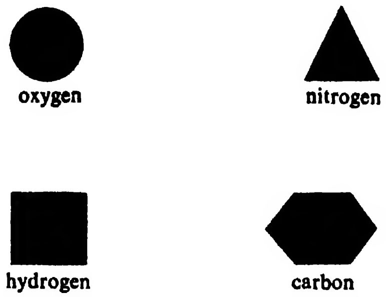


Fig. 2.2. Symbols used in this chapter to represent four primary elements in living substances.

transporting medium and (4) plays a great role in regulating the effects of external temperature.

B. **INORGANIC SALTS.** Though often present in insignificant quantity, the inorganic salts play following important roles —(1) help in certain chemical reactions, (2) serve as precursor material for the synthesis of certain essential molecules (e.g. DNA), (3) take part in the formation of supporting and protecting structure of the soft parts (e.g. bone).

II. **ORGANIC COMPOUNDS.** Following types of organic compounds exist in living substances—(A) carbohydrates, (B) lipids, (C) proteins, (D) nucleotides, (E) vitamins. In addition to these there are organic acids, alcohols and steroids, which are synthesised from other molecules.

A. **CARBOHYDRATES.** These compounds contain carbon, hydrogen and oxygen atoms in their molecules, and the common trend of chemical composition is $C_n\ (H_2O)_n$. The carbohydrates serve as *fuel* and *structural material.* Most of the carbohydrate molecules are very large with a molecular weight of 500,000 or more. Each molecule is made up of numerous similar units. Each unit is called *sugar*. The carbohydrates may be (1) *monosaccharides*, (2) *disaccharides* and (3) *polysaccharides*.

1. **Monosaccharides.** Carbohydrate molecules which contain six or lesser number of carbon atoms are included in this group. The best examples are glucose, galactose and fructose (Fig. 2.3). All of them have the same molecular formula and are called *isomers*. They differ only in the arrangement of their hydrogen atoms. Of these three, glucose is most important, because it is the basic transportable form of fuel. It is used as fuel to be utilised during cellular respiration and to supply the energy to the organism for performing its life activities.

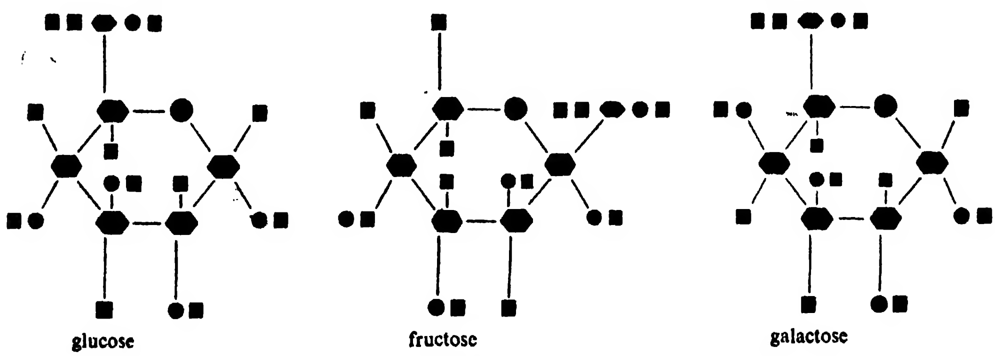


Fig. 2.3. Models of monosaccharides.

2. **Disaccharides.** These are formed by the linking up of two monosaccharides by an oxygen atom between them. The well-known disaccharides are sucrose and maltose (Fig. 2.4). Sucrose is composed of a glucose unit and a fructose unit; maltose results during the breakdown of starch (a polysaccharide).

3. **Polysaccharides.** These are very large carbohydrate molecules, containing series of monosaccharide units. Three

important polysaccharides are (*a*) *starch*, (*b*) *glycogen* and (*c*) *cellulose*.

(*a*) **STARCH.** These are storage products in plants and are formed by the conversion of excess sugar (Fig. 2.5). Starch is insoluble in water. When needed for the body in a watery medium starch is digested in the presence of enzymes called *amylase* and *maltase*, into simple sugar. The breaking down of starch or any other organic compound with the interaction of water is called *hydrolysis*. Starch provides the richest source of carbohydrate to mankind.

(*b*) **GLYCOGEN.** Instead of starch animals store sugar as glycogen. Excess sugar obtained from the plant starch is converted into glycogen which differs in structure from the plant starch. Glycogen is kept stored in muscles and liver. When required, it is quickly broken down into glucose. In lower animals, glycogen serves as the only source of reserve energy but in higher animals major energy reserves are the fats.

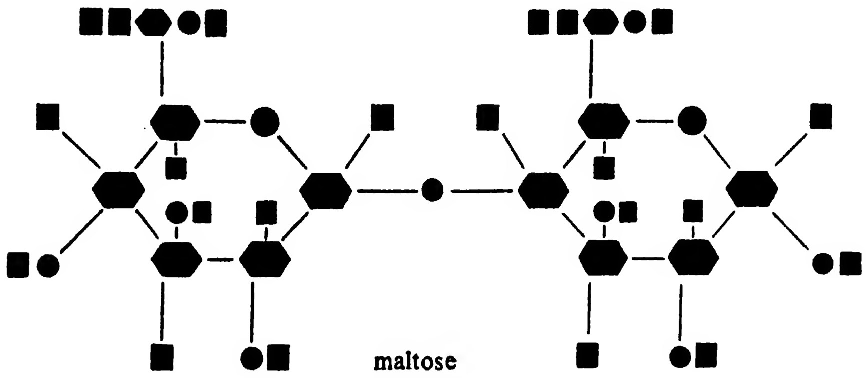


Fig. 2.4. Model of a disaccharide (maltose).

(*c*) **CELLULOSE.** This is a very important polysaccharide which is responsible for the formation of structural elements in plants. It is generally absent in animals except in a few cases (small quantities of cellulose are reported to be present in the skin of man). These are very long molecules, each of which may contain three thousand simple sugar units. Cellulose is digested only by an enzyme called *cellulase*, which is produced by certain organisms. In ruminants, the cellulose in the ingested plant material is digested by cellulase producing bacteria, which reside within their alimentary canal. Within the gut of termite, a flagellate, *Triconympha*, performs similar function.

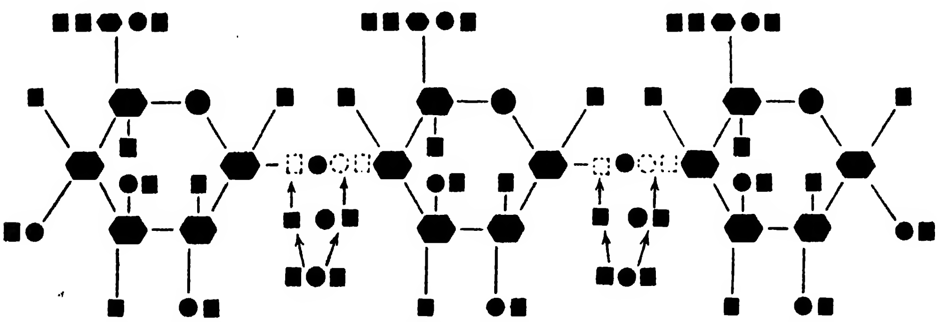


Fig. 2.5. Model of starch. During its break down water molecules add into arrow marked regions and convert it into glucose subunits.

B. LIPIDS. Lipids are the most common energy reserves in animals. It is stored as

round droplets in special kind of tissue called adipose tissue and serves the following important functions—(1) as reserved potential energy, (2) as heat insulating layer beneath the skin, (3) as protector of vital organs from mechanical damages and (4) as to meet the water requirements in many animals. Each molecule contains carbon, hydrogen and oxygen atoms, but their arrangements are entirely different from that of carbohydrates (Fig. 2.6). Here,

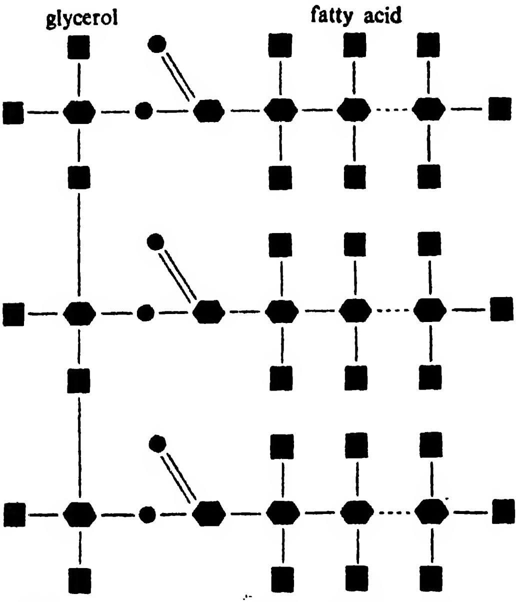


Fig. 2.6. Model of a representative fat molecule.

in each molecule hydrogen atoms are in greater proportion to oxygen than that in the carbohydrates and thus are concentrated source of potential energy. Moreover, during its burning (oxidation), more water is produced. The animals living in arid zones and unhatched chicks meet their water requirements from this water produced as a byproduct of the breakdown of lipids. Each lipid molecule is made up of one alcohol molecule and three molecules of fatty acid. The three fatty acids in one molecule of fat may be identical or may be different. The number of carbon atoms in fatty acid varies from 4–24, and the number is always even. Lipids may be of three types—(1) *Simple*, (2) *Compound* and (3) *Derived*.

1. **Simple lipids.** Fatty acids are combined with alcohols to form simple lipids. When the alcohol is glycerol it is called *true fat* and when it is other than glycerol it is called *wax*. The common examples of waxes are (*a*) *Beeswax*—Fatty acids are combined with myricil. (*b*) *Lanoline*—Fatty acids are united with cholesterol.

2. **Compound lipids.** When fats are combined with other non-fatty groups like phosphates, sulphates, sugar and amino acids. The examples are (*a*) *Phospholipids*—Fats with phosphoric acid and nitrogenous base. (*b*) *Glycolipids*—Fats with sugar and nitrogenous base. (*c*) *Amino lipids*. Fats united with amino acids. (*d*) *Sulpholipids*—Fats united with sulphur.

3. **Derived lipids.** These are products which are obtained from the breakdown of simple and compound lipids.

Fats which are eaten as food, are first emulsified by the action of bile salts produced in the liver. It is then hydrolysed by the action of an enzyme *lipase* which converts it into fatty acids and glycerol. As fats are insoluble in water emulsification is a necessary prerequisite for transporting it through a watery medium. The water-soluble form is also obtained by replacing one of the three fatty acid molecules with a phosphorus-containing molecule. The resulting substance is called *phospholipid*. It may be mentioned here that in man and some other animals, sometimes the carbohydrates are converted into fats.

C. **PROTEINS.** Proteins are the most important compounds which provide the building blocks of the living body. From hair to the nail of the toe, each and every part is made up of protein. It remains dissolved or suspended, either singly or with others in the living substance. When united with other kinds of molecules, they are known as *conjugated proteins*. Before entering into the details of protein structure, it is important to note that the diversity of protein in a living body is unique. Each structure in a living body is made up of a specific kind of protein. Nature of protein not only differs in each species but also no two individuals (excepting identical twins) possess proteins of identical structure. Such uniqueness of proteins in each individual is believable only when the complexities and possibilities of variety of protein molecules are understood.

Each protein molecule contains nitrogen in addition to carbon, hydrogen and oxygen atoms. Other elements, i.e. sulphur, phosphorus, iron and copper may also be present. The structure of protein molecule is very large and is folded into three dimensional shapes. The two simpler proteins—*insulin* and *beta-lactoglobulin* have the molecular formulae—$C_{254}H_{377}N_{65}O_{75}S_{6}$ and $C_{1864}H_{3012}O_{576}N_{468}S_{21}$. In spite of their large size the protein molecules are built up in an orderly fashion. Each chain is built up with simpler units called amino acids. Out of nearly eighty known amino acids, twenty are common in all living organisms. These twenty amino acids are built up in the following pattern. An *amino group* ($-NH_2$) unites with the *acid group* (COOH), by removing a molecule of water. Figure 2.7 shows the general plant of amino acids.

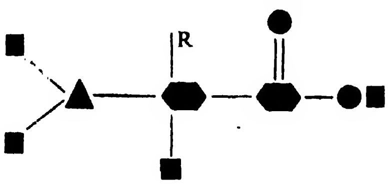


Fig. 2.7. General plan of amino acids 'R' varies in different amino acids.

The letter R represents the particular chemical group which remains associated with the amino acid. The structure of R varies in different amino acids (Fig. 2.8). As already mentioned, in a molecule of protein the amino acids are linked together in such a way that amino end unites with the acid end of another after removing the water molecules between them. Such union is called the *peptide bond.* When it is a combination of two amino acids it is called *dipeptide* and when many amino acids are united they form a *polypeptide.* Thus, like the twenty-six alphabets making a voluminous dictionary, innumerable combinations of amino acids form the diverse kinds of proteins. During the breaking down of protein, by the action of proteolytic enzymes, the long chains of amino acids are broken into shorter chains. Finally, the shorter chains are broken into constituent amino acids. A water molecule is inserted at the broken end. The chain of protein molecules which remain folded is extremely sensitive to various physical and chemical agents. When in contact with these agents they lose their characteristic folding. It is called *denaturation.*

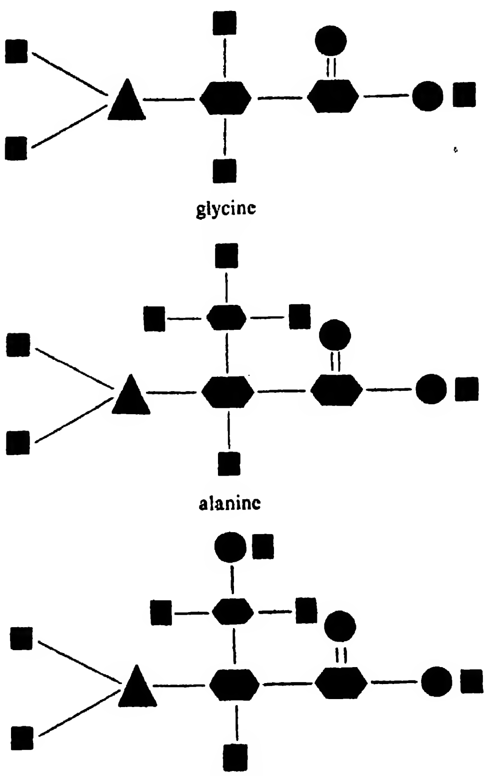


Fig. 2.8. Models of three different amino acids.

D. **NUCLEOTIDES.** Each nucleotide consists of a pentose sugar, a phosphate and one of the four bases. The pentose sugar is either *ribose* or *deoxyribose.* The ribose contains one oxygen atom more than deoxyribose. The phosphate is derived from phosphoric acid. Four bases which are present in the nucleic acids are nitrogenous and two of them are in the group called *Purines* and two are *Pyrimidines.* The purines are *adenine* and *guanine*, the pyrimidines are *cytosine* and *thymine* or *uracil.* Thus, there are four types of nucleotides, each type is characterised by a particular base. When one base unites with one pentose unit, they form a *nucleoside*, e.g. thymine with ribose = Thymidine; adenine with ribose = Adenosine. The sugar end of a nucleoside unites with the phosphate group to form a nucleotide unit, e.g. Adenosine monophosphate or AMP, Thymidine monophosphate or TMP.

Nucleotides act as (1) components of genetic system, (2) as energy conveyor and (3) as co-enzymes.

1. **Nucleotides in Genetic system.** Here nucleotides unite to form complex macromolecules called *nucleic acids*. Two types of nucleic acids are found (*a*) *Deoxyribonucleic acid* (*DNA*) and (*b*) *Ribonucleic acid* (*RNA*).

(*a*) **Deoxyribonucleic Acid.** Deoxyribonucleic acid or DNA is the most important chemical substance present in the living system. The chemical basis of heredity depends upon the working of this substance which is called the key molecule of life. The DNA is localised in the nucleus (on the chromosomes) and sometimes is seen in other parts, i.e. mitochondria.

Each molecule of DNA is made up of two strands or chains, each of which is formed by the alternate arrangement of deoxy sugar and phosphate groups (Fig. 2.9). The two chains are helically coiled as in a spiral staircase. This brings the two bases in between the two strands and in front of each other. Space between the two chains is such that one purine and one pyrimidine can fit together by the force of a weak hydrogen bond. This again is possible only when adenine pairs with thymine and guanine pairs with cytosine. Though the sequence of base in one strand varies in different organisms, the pairing of base is always the same. From microbes to man, everywhere adenine fits with thymine and guanine couples with cytosine. Thus the sequence of base in one strand acts as a *template* of the other strand. The findings of molecular biology in recent years have established that in the arrangement of pairing of purine and pyrimidine bases lies the code or blue print of 'building and working' of the living system. These codes are first of all transcribed into the nitrogen base sequence of RNA. That instruction is again translated to arrange different amino acids in proper sequence to form protein. The DNA can multiply and this involves self-replication. This property serves as the basis of reproduction in all living organisms. Another important property of DNA is that it is mutable. The sequence of nitrogen base pairing may undergo change. This results into the production of a code of different kind which results into the appearance of changed traits.

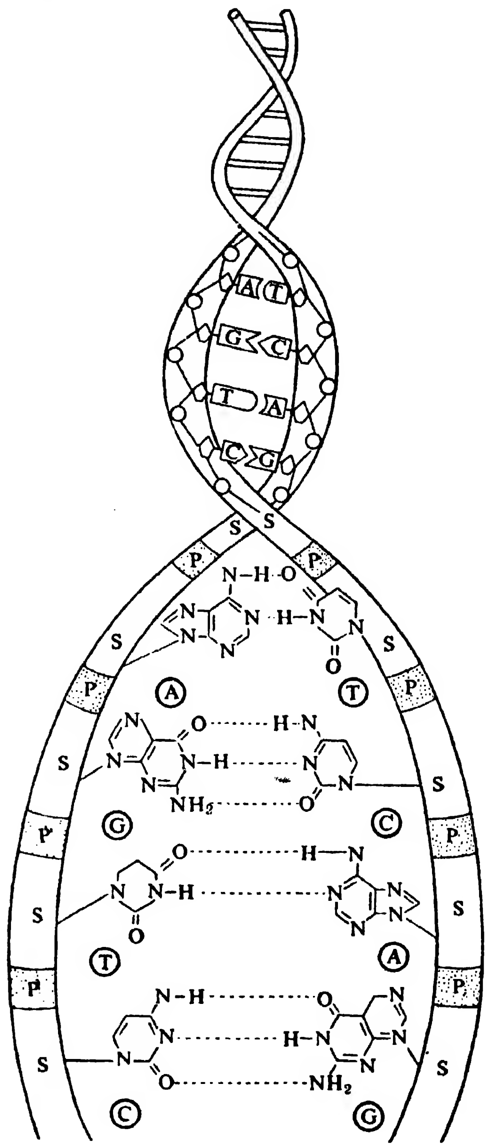


Fig. 2.9. Model of DNA showing structural and molecular configuration. The top portion depicts the double helical pattern with ring-like joints. The middle part represents the sequence of complimentary nucleotides. The details of the molecular arrangements with connecting hydrogen bonds are illustrated in the lower part. (Note that each helix is formed of a sugar phosphate backbone and four bases. Each base is connected with the sugar part and the two bases remain united by weak hydrogen bonds).

(*b*) **Ribonucleic Acid.** In most living forms ribonucleic acid or RNA is responsible for the synthesis of proteins. In a group

of viruses, it acts like DNA to serve as the material basis of inheritance.

STRUCTURE OF RNA. Long, thread-like molecules which are arranged usually in single strand but it may be coiled in several places to form helices. Sugar in the nucleotide is ribose sugar and of the pyrimidine bases the thymine is replaced by uracil, but the plan of pairing is same as in DNA, i.e. adenine with uracil and guanine with cytosine. According to their functional role in the process of protein synthesis, RNAs are classified into—*messenger* RNA, *transfer* RNA and *ribosomal* RNA.

NUCLEOTIDES AS CONVEYORS OF ENERGY. Nucleotides exhibit a tendency to couple with additional phosphate group. For example, *Adenosine monophosphate* (AMP) with a second phosphate group becomes *Adenosine diphosphate* (ADP), while the addition of a third phosphate group makes *Adenosine triphosphate* (ATP). This addition or union of additional phosphate groups requires a large quantity of energy which is available from respiratory fuels. This linking energy is called *high energy bond*. When ATP breaks into ADP and finally into AMP, this bounded form of energy is released and utilised by the cell.

Nucleotides as Coenzymes

The nucleotides which work as coenzymes, are complex substances which accompany the activity of an enzyme. In a chemical reaction within the body certain atoms are often transferred from one compound to another. An enzyme hastens the process and a coenzyme actually helps in transfer. Most of the coenzymes are produced from nucleotides, e.g. *Flavin mononucleotide* (FMN) and *Flavin adenine dinucleotide* (FAD). Both are formed by the union of flavin parts of vitamin B, Riboflavin with nucleotide derivatives. They work in transferring hydrogen atoms.

E. VITAMINS. These organic substances are never produced from carbohydrates, fats, proteins or nucleotides, but mostly taken directly from external sources. Some vitamins are of course synthesised in the body or are supplied secondarily by the micro-organisms living inside. The vitamins are required in very small quantities but are essential for the individual. Till the chemical nature of the vitamins were unknown, these substances were called in alphabetical names like, Vitamin A, B and so on. Formerly, it was detected that lack of vitamins in the diet produces various kinds of deficiency diseases. In recent years, it has been established that vitamins act by uniting with the protein part of the enzymes. It is also understood that vitamin requirement is not same in all organisms. A particular vitamin which is essential for a particular organism, may not be required by some other forms. The latter groups may be capable of synthesising it within their body. A list of vitamins with their chemical names, sources and deficiency diseases produced by them are mentioned in Table 1.

TABLE 1

Different vitamins, their chemical names, sources and diseases produced due to their deficiency

ALPHABETICAL NAME	CHEMICAL NAME	SOURCE	DEFICIENCY DISEASES
Vitamin A $C_{20}H_{29}OH$	Axeropthol	Milk, butter, carrot, green vegetables, fish liver.	Night blindness, eye troubles, resistance of mucous membrane to various diseases decreases.
VITAMIN B GROUP Vitamin B_1	Thiamine	Meat, unpolished rice, yeast.	Neuritis, muscular weakness, digestive troubles.
Vitamin B_2 or G	Riboflavin	Cheese, liver, egg, milk.	Prevents growth in young. Disturbs the utilisation of unsaturated fatty acids.
Vitamin B_6	Pyridoxin	Do	Do

TABLE 1 (contd.)

ALPHABETICAL NAME	CHEMICAL NAME	SOURCE	DEFICIENCY DESEASES
Vitamin B_{12}	Cobalamin	Liver.	Affects the formation of blood cells.
	Niacin or Nicotinic acid	Yeast, meat, milk.	Deficiency produces damage to the skin, intestinal epithelium, and nerves.
	Pantothenic acid	Yeast, meat, milk.	Deprivation produces dermatitis in chicken, prevention of growth in rat, need unknown in man.
Vitamin C	Ascorbic acid	Orange, lemon, fresh vegetables.	Causes scurvy. Retards skeletal growth.
Vitamin D	Calciferol and other sterols	Synthesised in the skin by the action of ultra-violet rays.	Creates abnormal deposition of calcium compounds, deficiency causes rickets.
Vitamin E	Tocopherol	Cereal germ oil.	Prevents abortion, sterility but precise function is not known.
Vitamin F	Linoleic acid	Occur in vegetable oil, specially in linseed oil.	Function is not clearly known.
Vitamin H	Biotin	Yeast, cane molasses, yolk, etc.	Human needs not known.
Vitamin K	Contains naphthoquinone compounds.	Human needs come from bacteria living in gut. Also available from spinach and other green vegetables.	Causes proneness to haemorrhage.
Vitamin P	Related to Flavanone, Hesperidin.	Citrus fruits.	Loss of resistance power of the capillary walls.

SUMMARY

The substance which constitutes all living bodies is known as PROTOPLASM. It is composed of four primary elements—Carbon, Hydrogen, Oxygen and Nitrogen. In addition, various other elements are present. These elements are organised into compounds which are of two categories—(*a*) Inorganic and (*b*) Organic. The important inorganic compounds are water and various salts. The organic compounds include chiefly carbohydrates, lipids, proteins, nucleotides and vitamins.

CHAPTER 3

Chemical Background

The study of the constituents of living matter tells us that it is made up of elements which are also present in the non-living matter. Each matter has some properties of its own and this is the expression of activities which are going on at the levels of molecules and atoms (Fig. 3.1). How does this expression occur at the molecular level within a living system?

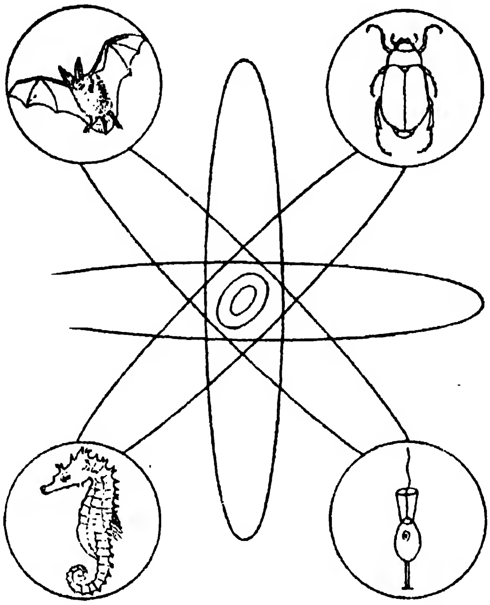


Fig. 3.1. All living forms are made up of atoms.

It is evident from the preceding chapter that living substance, protoplasm, is made up of large number of inorganic and organic compounds. The working of these compounds helps in the maintenance of a dynamic steady state. By two steps—metabolism and responsiveness, the living body maintains this dynamic steady state and both the steps are carried out by innumerable chemical reactions of the different compounds present in the protoplasm. Life is thus rightly defined as 'uninturrupted chains of chemical reactions'.

It was calculated by Hofmeister, that a cell of liver contains approximately 230,000,000,000 molecules of different compounds. These molecules are in constant dynamic state. Some of them synthesise their own material (anabolism) and some are engaged in breaking down of materials for liberating energy (katabolism). A background knowledge of chemistry is necessary to understand this chemical make up of living body.

I. **MATTER.** It is defined as some thing which occupies space and has some weight. Matter may be formed of one kind of substance or of different kinds of substances. Matter may exist in any one of the three states—solid, liquid and gaseous. A matter may change from one state to the other. When this happens due to temperature and pressure, it is called a *physical change*, which does not alter the basic characteristics of the matter. A second type of change may alter the fundamental characteristics of the matter which is called *chemical change*.

II. **ELEMENTS.** When matter is made up of same kind of substances it is called

an element. An element cannot be further broken down by chemical means. More than hundred elements are known to occur and 25% of them are present in the living body.

III. **ATOMS, MOLECULES AND ENERGY.** Each element is made up of a particular kind of atoms. Atom is defined as the smallest part of an element which participates into the chemical combinations with other elements. Atom consists of a positively charged *nucleus* in the centre and one or more negatively charged *electrons* around it. The nucleus, which constitutes the mass of the atom, is composed of positively charged *proton* and electrically neutral *neutron*. The electrons are in constant motion along a definite orbit around the nucleus. There is a limit to the number of electrons which may be present in a particular shell. This is expressed by the formula—maximum number$=2\times n^2$. Here, 'n' represents the number of shells in the atom.

It means that if the first shell contains 2 electrons, second shell may hold 8 electrons, third shell may retain 18, fourth shell 32. But according to another rule the outermost shell cannot possess more than eight electrons. This means that in an atom having four shells, the outer one though able to hold 32 electrons will not have more than 8. Thus, atoms which have the full number of electrons are called *stable atoms*, e.g. helium, neon, argon. On the contrary, the atoms which do not have the complete set of electrons in the outer shell combine with other atoms by gaining or losing electrons and thus retain stability (Fig. 3.2). The atoms which

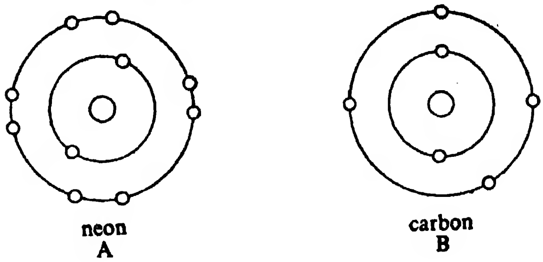


Fig. 3.2. (A) Stable atom. (B) Unstable atom.

lose electrons are called electro-positive and the atoms which gain electrons are electro-negative. This tendency of atoms to gain stability is the basis of all chemical reactions in which atoms of different elements unite with each other (Fig. 3.3).

Such union of two or more atoms results in the formation of *molecule*. Molecules are defined as the smallest part of a substance which can remain independently and exhibit the properties of the original substance. The attachment of atoms needs *energy* which comes from external source. Thus within a molecule, the atoms retain some form of energy as the binding force. When in a chemical reaction this bond breaks, energy is released. The binding capacity varies in different atoms and is fixed for each kind of atom. Thus

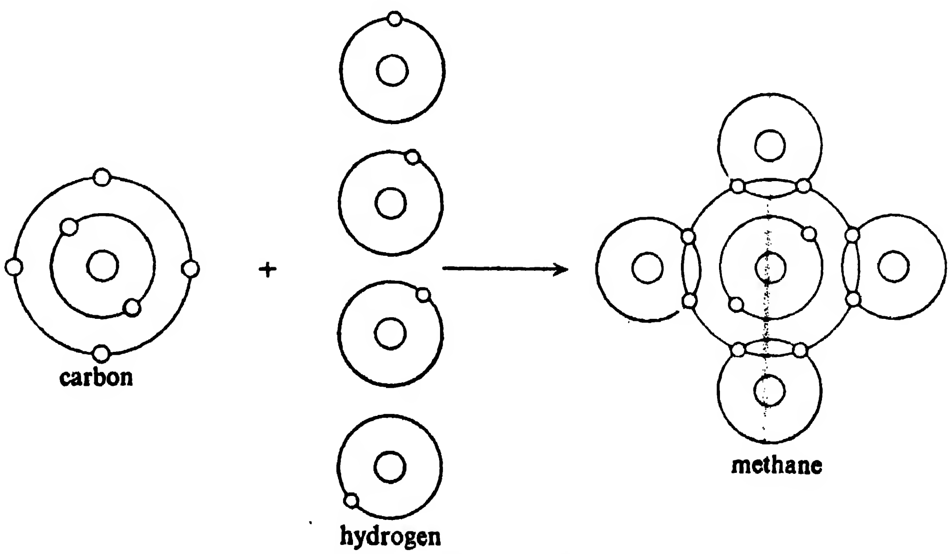


Fig. 3.3. The atoms unite to form a molecule.

hydrogen has one bond and oxygen, nitrogen, carbon possess 2, 3, 4 bonds respectively. The nature of a molecule depends upon the number, type and the spatial arrangement of the atoms. Some very large molecules may contain thousands of atoms. Some atom may be present in two different molecules but in different arrangements. Such molecules which have same number and kind of atoms but with different arrangements are called *isomers* (as seen in the case of monosaccharides).

IV. **CHEMICAL REACTIONS.** All compounds are formed either by the union of atoms or of molecules. When atoms of one kind unite to form a compound, they remove the outer electrons from other atoms. This gain in one and loss in other affect the electronic charge in them and they are held together by opposite charges. These charged atoms are called *ions* (Fig. 3.4) and they are held together by ionic bonds. The compounds produced in this way are called ionic compounds. When molecules of the ionic compounds are dissolved in water and are dissociated from one another they still retain the properties of the substance.

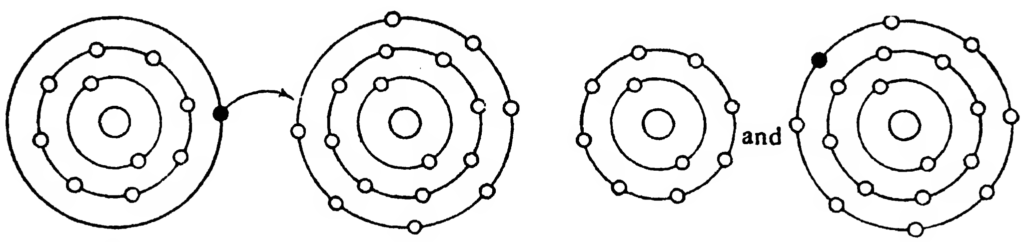


Fig. 3.4. Formation of sodium and chloride ions from sodium and chlorine.

When two or more molecules are mixed they interact in such a way that a different kind of substance is formed. This interaction of molecules is called **chemical reaction.** Four types of chemical reactions are known.

A. **Exchange reaction.** Atoms interchange their position in the contact of two molecules.

$$H-Cl+Na-O-H= \quad Na-Cl+H-O-H$$

B. **Synthesis reaction.** Several molecules unite together to form a single molecule.

$$CO_2+H_2O=H_2CO_3$$

C. **Decomposition reaction.** This is just opposite to synthesis reaction. Here one molecule breaks up into smaller molecules.

$$H_2CO_3=CO_2+H_2O$$

D. **Reversible reaction.** In this type of reaction, both the synthesis and decomposition continue simultaneously. For example, when Hydronium ion (H_3O) and bicarbonate (HCO_3) are kept together in a test tube, they react in the following way:

$$H_3O + HCO_3 = H_2O + H_2CO_3$$

hydronium + bicarbonate = water + carbonic acid

As H_2CO_3 decomposes into CO_2+H_2O, the carbon dioxide escapes in the air.

But in a closed chamber, this CO_2 reacts with water to form H_2CO_3 (carbonic acid), which in turn again combines with water to form Hydronium ion and bicarbonate ion. Thus, reactions are taking place in two directions and it ultimately reaches an equilibrium. Such reactions are indicated by double arrows. Thus we can write the formula in the following way:

$$H_3O+HCO_3 \longrightarrow H_2O+H_2CO_3 \quad (i)$$

again,

$$H_2CO_3 \longrightarrow H_2O+CO_2 \quad \ldots (ii)$$

Overall reaction

$$H_3O+HCO_3 \rightleftharpoons 2H_2O+CO_2 \quad \ldots (iii)$$

In some of these reactions where new molecules are formed, energy is stored, in others during breakdown of the molecules,

energy is released. The reaction where energy is stored is called *endergonic* or energy regaining, whereas when energy is released it is called *exergonic* or energy-yielding reaction. All these chemical reactions depend upon certain factors—temperature, pressure and concentration of reacting molecules. Within a test tube all chemical reactions are activated by heat energy. There are certain substances called *catalysts*, which reduce the amount of activation energy needed. Living system is provided with a vast array of catalysts, called *enzymes*. These enzymes help all chemical reactions to occur quickly and at safe temperature (Fig. 3.5).

V. **ENZYMES.** Enzymes are proteins and they act as catalytic agents. They are found only in the living body. They speed up different chemical reactions but remain unchanged at the end of reactions. The word enzyme was first coined by Kuhne in 1880. Uptil now more than 700 enzymes are known from different living systems. All enzymes are not seen in all living bodies. On the contrary, there exists a definite enzymatic pattern in relation to the anatomical plan of each species in response to its particular adaptation. Enzymes may be named on the basis of their substrates (substance on which enzyme acts). For example, the enzymes which split proteins are called proteolytic enzymes, which break down carbohydrates are called amylolytic and which take part in the breakdown of fat are called lipolytic enzymes. Enzymes are again named according to the nature of the compound on which they are effective. For example, enzymes which act on proteins are called proteases, which act on nucleic acids are called nuclease etc. Enzymes are specific in their action, i.e. one enzyme is capable of taking part in one chemical reaction only. Enzymes act with a great speed and a single enzyme molecule may be used repeatedly. A minute amount of enzyme can break down a very large quantity of substrate.

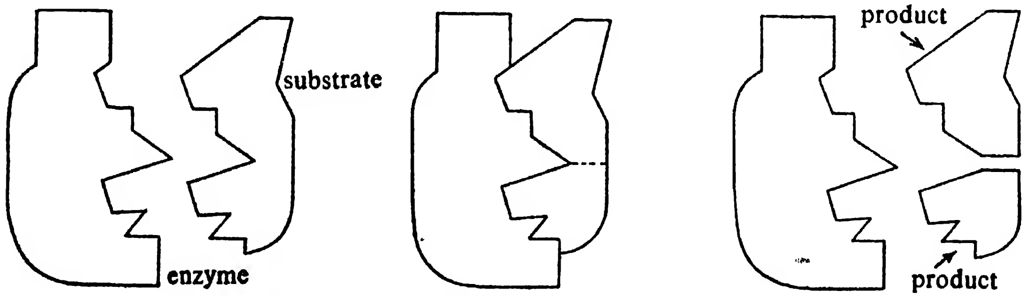


Fig. 3.5. Model of enzyme action.

VI. **MIXTURES AND COMPOUNDS.** A mixture is formed by two or more substances where each substance retains its property. Compounds are also formed by the union of two or more substances but the properties of the compound become different from those of its constituents. Within a mixture the properties of the constituent may vary but in the compound it is always the same. Following mixtures are important from the point of view of biology.

A. **Solution.** It is the homogeneous mixture at molecular level of two or more substances having different molecular orientations. Generally, it is formed by the mixture of a solid or gas in a liquid. The liquid is called the solvent and the substance which is dissolved is known as the solute. Water is the major solvent in living systems.

B. **Suspension.** It is a mixture which consists of very minute solid particles scattered in a liquid dispersion medium. A mixture of sand and water is a perfect example of suspension. The constituents of a suspension separate by the action of gravity.

C. **Emulsion.** It is a mixture of a liquid in a liquid. Here the two liquids remain separate in minute droplets. Oil in mixture with water forms emulsion. Two such substances are always intimately

united. But this may be augmented with the addition of an emulsifier. Within the body the bile salts act as emulsifying agent.

D. **Colloids.** The colloid is the mixture of particles which remain larger than in solutions but smaller than in suspension. The particles in a colloid never precipitate down at the bottom as in case of suspension, e.g. milk (colloid of fat and protein in water), fog (colloid of water in air). The particles may be seen under microscope but cannot be filtered through ordinary filter paper.

The protoplasm is partly colloid and partly suspension. Many substances remain dissolved in the watery medium of protoplasm which also contains numerous insoluble *materials* in colloidal state. The protoplasm is thus a colloid of both solid and liquid in a liquid medium. The colloidal consistency of protoplasm exhibits following features:

1. **Brownian Movement.** Gravitational force always tends the colloidal particles in the protoplasm to settle down, but finer particles in the suspension, which are always under constant thermal agitation kick them. This counteracts gravitational force and produces a rotating motion called Brownian movement.

2. **Similar Electric Charges.** The dispersed colloidal particles possess similar electrical charges which repel each other. This together with Brownian movement causes the colloidal particles to remain in dispersed state.

3. **Sol-Gel Conversion.** The cellular colloids have the ability to change from a solid to liquid phase. When water is withdrawn. the particles stay together and form a stiff *gel* phase. Immediately with the coming of water in between the particles they disperse and the fluid *sol* phase appears.

4. **Formation of Membrane.** The colloids within living system always tend to form a membrane, which separates inner part from the outer environment. The membrane thus makes the interphase by tight packing of molecules. When broken due to injury it is soon repaired before the inner contents flow out.

The membrane regulates the flow of different materials. It has been noticed that though many small molecules are not permitted yet several large molecules are allowed to enter. Such selective filtration involves in one hand physical processes like osmosis and diffusion and on the other hand complicated chemical reactions.

SUMMARY

The work in protoplasm at molecular level involves synthesis of own material in one hand and breakdown of the same in the other. The chemical reactions within protoplasm are guided by the same laws which work in non-living matters. The presence of several enzymes in the protoplasm facilitate the reactions.

The protoplasm contains different substances which remain in the state of *solution, suspension, emulsion* and *colloid*. For the following properties—*Brownian movement, identical charges, sol-gel conversion* and *membrane formation* the colloids play important role in living system.

PART TWO

SIMILARITIES WITHIN DIVERSITIES

The secret of Nature's beauty lies in the existence of diversities in living world. A bird has no similarity with a dragon fly, a squirrel never resembles a cat or a dog. The examples of diversities are numerous and in subsequent chapters we will learn more about them. It will also be revealed that diversity exists to such an extent that no two animals, even of the same kind are exactly alike (of course, the identical twins are exceptions).

In this part we will examine the similarities which exist within diversities. The modern concept of unity includes unity in both plant and animal organisation, but here we will restrict our discussion to animal organisation only.

CHAPTER 4

Cell—The unit of living organisation

One of the characteristics of protoplasm is that it never exists in a continuous state. It always forms small functional units called—*cells*. The cell was first seen by Robert Hooke in 1665 through the microscope made by himself (Fig. 4.1). Since then in the last 300 years, it has been learnt that all living bodies are made up of cells and the functioning of an individual is the result of combined and co-ordinated efforts of all its cells. To understand the problem of life processes, one must explore the cell—its structure, shape, size, number and function. The study of cell, which started as *cytology*, has now become the pilgrimage of men from different disciplines and thus a new horizon has come in biology which is called *cell biology*.

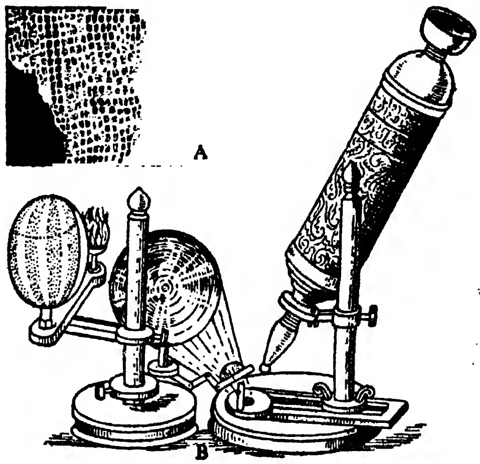


Fig. 4.1. The cell (A) as seen by Robert Hooke in 1665 through the microscope (B) made by him.

The word 'cell' (Latin *cellula*=a small apartment) means compartment. In fact, this term was coined by Robert Hooke to describe the structures of the cork

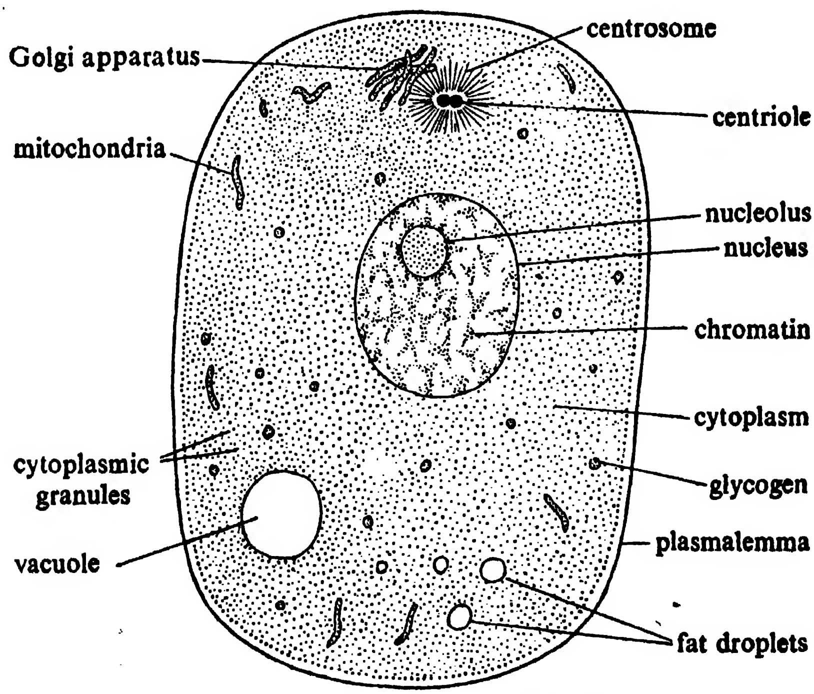


Fig. 4.2. Diagrammatic view of an animal cell under the light microscope. All the parts shown above are not necessarily present in all animal cells.

which he observed under his microscope. Hugo von Mohl was the first biologist to recognise the importance of the *protoplasm* as the living contents of the cell. Robert Brown noticed the existence of rounded bodies within the central region of the epidermal cells of orchid leaves. He coined the term *nucleus* to these centrally located bodies. After the discovery of the existence of nucleus M. J. Schleiden and T. Schwann profounded the *Cell-theory* which postulates that all living organisms are made up of cells, i.e. they are essentially cellular in nature. Since then different biologists contributed much on the biological nature of the cell. Studies by different workers through light microscope have revealed the following structures in almost every animal cell (Fig. 4.2). I. Plasmalemma, II. Cytoplasm and III. Nucleus. The cytoplasm contains several structures which are collectively known as cytoplasmic organelles. The structure and function of the cell are carefully determined by the critical examination of entire cell and by isolation of its parts. The needs of these studies required various methods and techniques. The introduction of electron microscopy added a new dimension to the study of cells and its structures were known in greater details (Fig. 4.3).

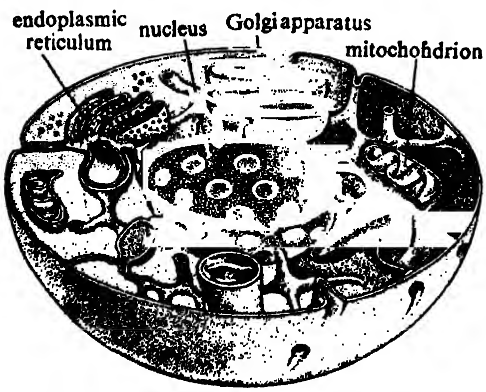


Fig. 4.3. A three-dimensional diagrammatic view of half of an animal cell showing some of the structures.

An account of different components which are present in the animal cell is given below. It must be remembered that all the structures, which are described, are not necessarily present in all the animal cells.

COMPONENTS OF ANIMAL CELL

I. **PLASMALEMMA.** This is the outermost limiting membrane of the cell. The concept of plasmalemma developed long before it was actually seen. The structure of plasmalemma was revealed only after the use of electron microscope. It is very thin, nearly 75 Å (1 Å $= \frac{1}{10,000}$ micron $= \frac{1}{10,000,000}$ mm) and contains a double layer of lipid molecules which remain sandwitched between two layers of protein (Fig. 4.4). The two lipid layers

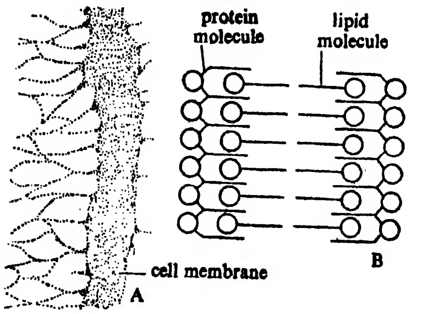


Fig. 4.4. A. Showing the structure of cell membrane as seen through electron microscope. B. Chemical make up of cell membrane.

are 35 Å thick and each protein layer is of 20 Å in thickness. The plasmalemma is extremely elastic and this elasticity is due to the folded nature of its protein molecules. The appearance of the cell surface depends upon the nature of the cell, i.e. whether it is free or in contact with other cells. Even when the cells are in intimate contact, they remain a few Å apart and the gap is filled up with extracellular material (ECM). The plasmalemma is extremely unstable and is always reformed. The cell surface is perforated and the pores lead into canals. The lining of these canals is in continuation with the plasmalemma. These canals go deep into the cytoplasm and are associated with other components of the cell which also are lined by plasmalemma like lipo-protein. The plasmalemma performs several functions which are listed below:

A. It separates the inner content of the cell from the outer environment.

B. It acts as a selective semipermeable membrane to control the entrance and exit of different molecules. Sometimes the membrane, in addition to selection, helps in the entrance and exit by a system of active pumping. The two functions,

namely, the absorption and excretion of molecules are carried out in the membrane by the action of enzymes and an energy-rich substance called *Adenosine triphosphate* (ATP). The permeability of membrane depends upon several factors—age and metabolic state of the cell and the condition of external environment.

C. It helps to maintain the isotonic condition by regulating osmosis.

D. In addition to selective absorption of molecules, the plasmalemma may ingest solid or liquid substances by the following two processes—(1) *Phygocytosis* and (2) *Pinocytosis* (Fig. 4.5).

and is responsible for the movement of the cell.

F. Plasmalemma may have specialised substances around it for giving mechanical support to the individual, e.g. chitin, keratin and cellulose.

G. It is responsible for maintaining the shape of the cell.

II. **CYTOPLASM.** In the light microscope, cytoplasm appears as a semi-fluid, complex, elastic and heterogeneous material. In some cells the cytoplasm is distinctly divided into an outer stiff *ectoplasm* and an inner fluid and actively mobile *endoplasm*. The endoplasm contains various inclusions or organelles having diverse functions. The following structures are generally seen in the cytoplasm of all cells though it may be that some organelles are the characteristics of certain cells only.

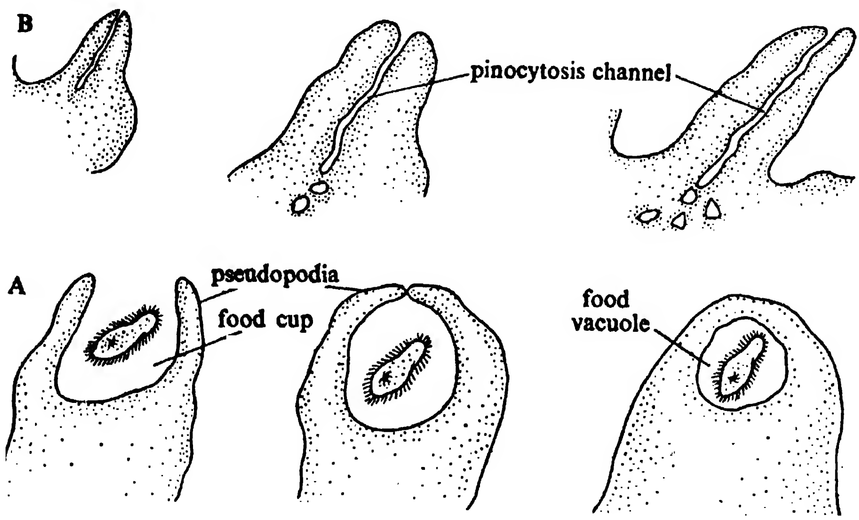


Fig. 4.5. Three stages of phagocytosis (A) and pinocytosis (B).

(1) **Phagocytosis.** It involves ingestion of solid particles. This is done by the extension of plasmalemma and cytoplasm around the particle in the form of a pouch. The pouch finally detaches it from the outer membrane and is drawn inside as a vacuole, the wall of which is formed by the plasmalemma. Immediately with the intake of such a vacuole in the cytoplasm, the plasmalemma of the projected ends unite and the membrane becomes continuous. Phagocytosis is common in certain protozoans and in the amoeboid cells of higher animals.

(2) **Pinocytosis.** The phenomenon involves in the ingestion of liquid droplets in the same process as phagocytosis, the only difference is that the pouch is much smaller.

E. Plasmalemma is extremely sensitive

A. **Ground substance.** The cytoplasm contains a ground substance or *hyaloplasm* in which various organelles are dispersed. It includes, either in dissolved or suspended state, various reserve food granules, oil droplets and numerous thin fibrils.

B. **Endoplasmic reticulum or Ergastoplasm**. It is present as a system of membranous network in the ground substance of cytoplasm. These membranes begin from the plasmalemma pore and are structurally similar to plasmalemma. The membranes occur in pairs and thus form canals. These

canals are in continuation with various organelles and nucleus. The endoplasmic reticulum is found to occur in three forms —*cisternae*, *vesicles* and *tubules*. The cisternae are elongated, flattened and parallelly arranged. The vesicles are circular and the tubules have variety of shapes.

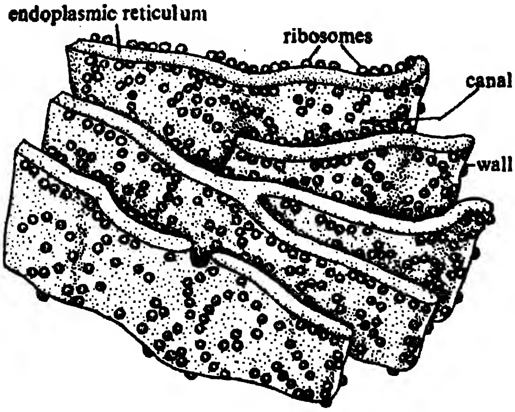


Fig. 4.6. Three-dimensional model (diagrammatic) of a part of the cytoplasm to show endoplasmic reticulum and ribosomes. The lining of endoplasmic reticulum forms network of canals. Ribosomes are seen on the wall of these canals.

C. **Ribosomes.** These are very small round bodies, which either remain scattered in the ground substance or are arranged in a linear fashion along the wall of the endoplasmic reticulum (Fig. 4.6). Ribosomes contain a special type of RNA. Some of the ribosomes remain attached to a single messenger RNA molecule and are called *polyribosome*, on which proteins are synthesised. When isolated the ribosomes are often accompanied by bits of endoplasmic reticulum. This fraction is called *microsome*.

D. **Mitochondria or Chondriosomes.** These small bodies are present in all cells excepting bacteria. The size varies from 0·2 μ to 8 μ. The mitochondria may be filamentous, rod-shaped, dot-like or oval. These mobile enzyme packets are usually evenly distributed throughout the cell. In certain cells, during synthesis, the mitochondria may assemble at the site of synthesis. The number of mitochondria in a particular cell type is always constant. The mitochondria often multiply but the exact mode of division is not known. In a living cell, these bodies can be stained by Janus green B. The study with electron microscope reveals that each mitochondrion is covered by a double membrane of protein and lipid. The outer membrane forms the smooth covering and the inner membrane gives rise to ruffled projections towards the interior to give a shelf-like appearance called *cristae* (Fig. 4.7). There are spherical granules in the cavity of the mitochondria which collect calcium and possibly magnesium needed for mitochondrial activity. The inner surface is filled up with a liquid, containing enzymes, mainly for cellular respiration. In addition, it contains RNA, vitamins and co-enzymes. Recently, it has been discovered that mitochondria also contain some amount of DNA. Mitochondria remain in close association with other components of the cell and exchange necessary substances.

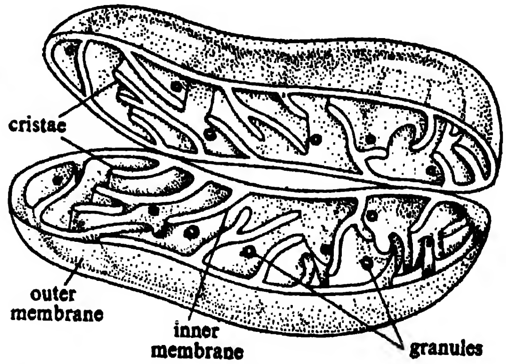


Fig. 4.7. Diagrammatic view of a mitochondrion (longitudinally splitted). The granules are for collecting calcium and magnesium, which are necessary in the work of mitochondria.

It is regarded as the power house of the cell and is involved in doing two important functions—*oxidation* and *phosphorylation*. Through oxidation it breaks down the carbohydrates, proteins and fats. The energy thus released passes through a number of reactions into other phosphate containing molecules. This stored energy remains bound in *Adenosine triphosphate* or ATP. In this form it is transported by the mitochondria to a particular site of the cell where energy exchange is going on.

E. **Golgi apparatus.** The Golgi complex was discovered by Camillo Golgi, an Italian physician. It is best seen in cells having secretory functions. It is visible only after special treatment with osmic acid and silver salts. Its electron microscopic structure is like a collection of paired smooth surfaced membranes and small sacs with a fluid in their inner space (Fig. 4.8). The Golgi vesicles

are in contact with the cisternae of endoplasmic reticulum. Its function is not

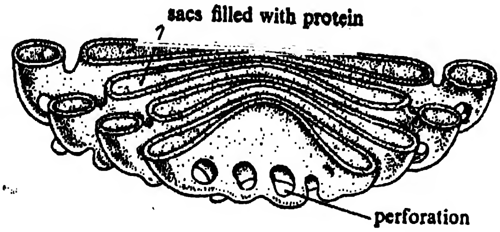


Fig. 4.8. Three-dimensional model of a portion of Golgi apparatus in cross-section.

properly understood, but it is believed to be involved in the synthetic process and also involves in "packaging" of proteins produced in cells.

F. **Vacuole.** The vacuoles appear as round bodies of different sizes. It is bounded by a plasmalemma like membrane. It contains water and various water-soluble substances. Some vacuoles may have special excretory functions and some may contain food particles. The general function of vacuoles is to regulate the osmotic pressure.

G. **Centrosome.** This is seen only in the animal cells. Under a light microscope, it is seen to contain two small round

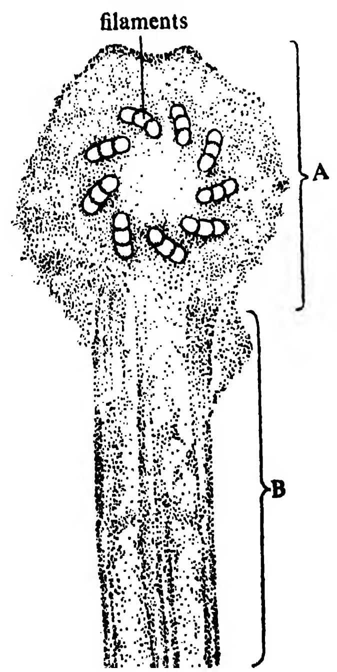


Fig. 4.9. Structure of centrosome under electron microscope. (A) Centriole in cross-section. (B) Centriole in longitudinal section (both diagrammatic).

central bodies called *centrioles*. Electron microscope reveals that each centriole is made up of nine groups of filaments which form a circle. Each group includes three filaments (Fig. 4.9). The centrosome plays an important part in cell division by organising the formation of spindle.

H. **Lysosome.** Lysosomes are small mitochondrion-like bodies with densely packed granules and concentric membranous covering (Fig. 4.10). It contains certain enzymes like phosphatase which take

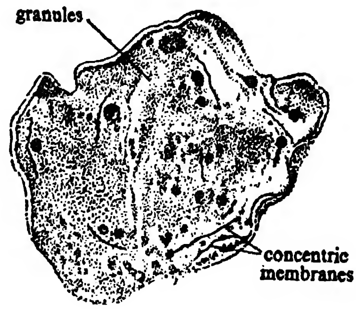


Fig. 4.10. Diagrammatic figure of lysosome based on an electron micrograph.

part in the breakdown of different cell substances. These enzymes are collectively known as *cathepsin*. These are released generally at the time when it is necessary to break down the cell itself. It is abundantly seen in the cells of amphibian larval tail, where considerable cellular breakdown occurs at the time of metamorphosis. These enzymes also help in the breaking of ingested cellular material.

I. **Plastids.** These organelles are the features of plant cells, but many lower animals, e.g. *Euglena* also possesses plastids (Fig. 4.11). The plastids which contain

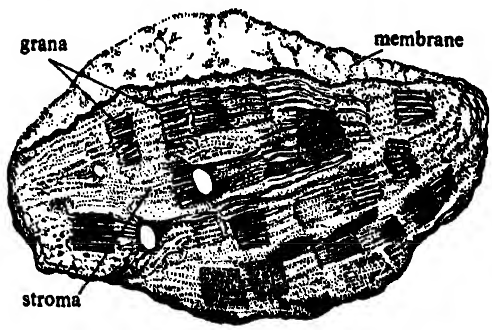


Fig. 4.11. Diagrammatic vew of a chloroplast as seen through electron microscope. Note that chloroplast contains outer and inner membranes. The inner membranes are densely packed and known as *Grana*. Grana lie in the colourless proteinaceous matrix, known as *stroma*.

green colouring pigment, chlorophyll (chloroplasts), are responsible for trapping energy from sunlight to synthesise carbohydrate food.

III. **NUCLEUS.** The nucleus is the most important structure of the cell. When the nucleus is distinct, the cell is called *eucaryotic cell*, but in forms like bacteria where definite nucleus is lacking it is regarded as *procaryotic cell*. The nucleus is usually spherical but may be of other shapes too (Fig. 4.12). The size of the

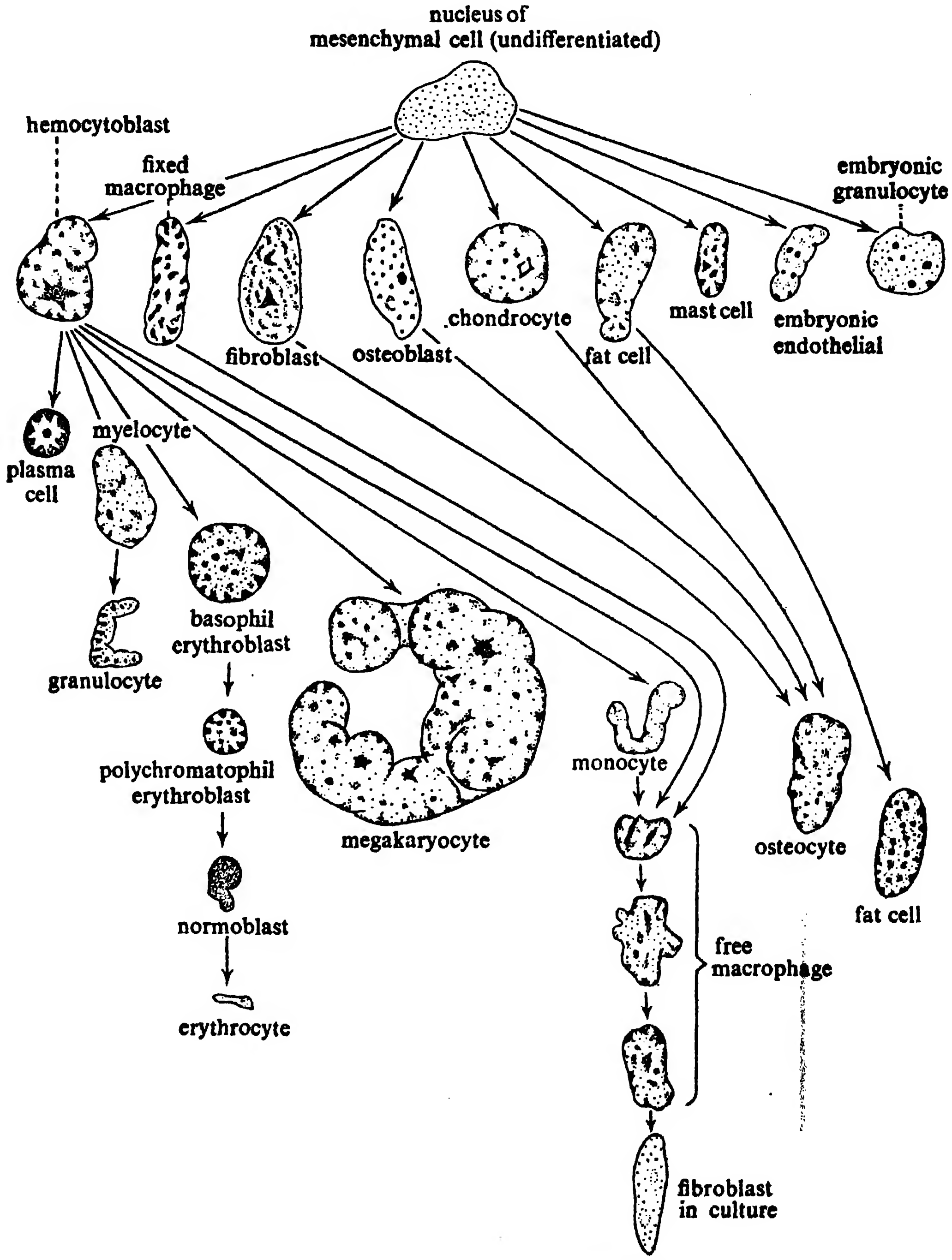


Fig. 4.12. Figure showing different types of nuclei. The cell membrane and cytoplasm are excluded to illustrate only the configurations of nuclei. Here all the nuclei are derived from the undifferentiated mesenchymal cell nucleus.

nucleus is usually proportional to the size of the cell. The nucleo-cytoplasmic ratio lies between 1 : 7 and 1 : 10. Generally, one nucleus is present in each cell, but there are cells with more than one nuclei.

The nucleus consists of following parts— (A) *nuclear membrane*, (B) *nuclear sap*, (C) *chromatin bodies* and (D) *nucleolus* (Fig. 4.13).

A. **Nuclear membrane.** Electron microscopy has revealed that nuclear membrane possesses structures identical

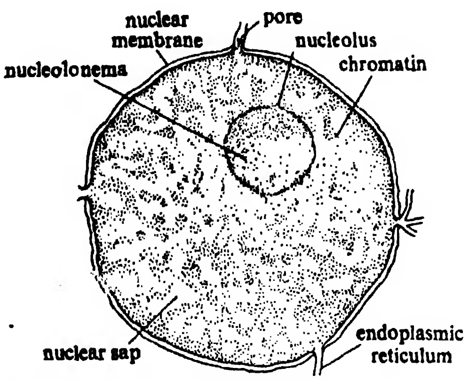


Fig. 4.13. Structure of nucleus as seen under electron microscope (diagrammatic).

to the structure of plasmalemma and other membranous structures of the cell. There are number of pores on the surface of the nuclear membrane through which different substances may pass in and out of the nucleus. Each pore has a central knob like diaphragm, which regulates the expansion and contraction of the pore.

B. **Nuclear sap.** The nuclear sap or *nucleoplasm* is made up of a gel-like substance in which different other structures of the nucleus remain suspended. It acts as a pool of various substances which are either used or produced by the different components of the nucleus. During division, dehydration of the nuclear sap occurs.

C. **Chromatin bodies.** These are present in the nuclear sap as beaded or thread-like structures. In a cell which is not dividing these bodies are seen only after suitable staining with the basic dyes. These bodies contain DNA, some amount of RNA, a protein called *histone* and certain enzymes such as *alkaline phosphatase.* During division the chromatin bodies condense and thicken to thread-like structures called *chromosomes* (Fig. 4.14). The chromosomes are paired structures and are evenly distributed during ordinary cell division. The chromosomes contain

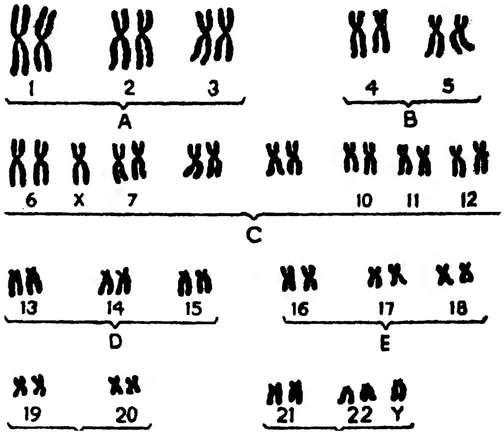


Fig. 4.14. Showing the 23 pairs of chromosomes of a normal human male. The chromosomes were photographed from a cultured leucocyte arrested at metaphase by colchicine and were consequently arranged as karyotype (Chicago conference, 1966) in different groups (A–G) according to length, number according to the position of centromere. Chromosomes X and Y respectively belong to groups C and G. Karyotype of a normal female has two X chromosomes in group C while her group G includes no Y chromosome at all (Courtesy: Dr. Sudhangsu Ghosal).

genes which bear hereditary traits (Fig. 4.15). The gene is not visible as a discrete body. The dark bands of the chromosomes (*euchromatic regions*), represent the sites of the genes. The chemical analysis of chromosomes has now established that it is the DNA part which works as bearer of hereditary characters.

D. **Nucleolus.** Nucleolus appears as a dense spherical mass inside the nucleus. The number may be one or two. It is rich in RNA. The number of nucleolus is fixed per nucleus and for a given type of cell. The nucleolus contains network of dense material called *nucleolonema* and coarse granules called *chromatin.* The nucleolus is visible only when the cell is not dividing and is believed to play an important role in the synthesis of ribosomal RNA. At the onset of division it dissolves. After division one particular chromosomal region organises it again.

CELL FUNCTION

The description of different cellular components may lead to this erroneous idea that each component probably carries

its activity independently. It is not so. All the cell organelles work together and

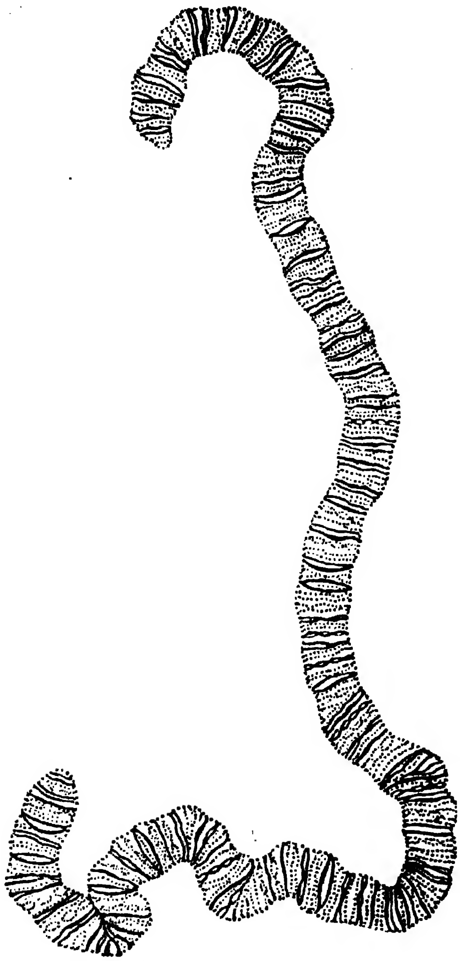


Fig. 4.15. A single salivary gland chromosome of *Drosophila*. Note the dark and light bands on its surface.

their work is absolutely dependent upon each other. The working of the entire cell is the cumulative expression of the working of its different components.

Within a multicellular body there are millions of cells, which differ in their shapes and functions. Whatever may be the duty of an individual cell, they work in a common plan. The working of a cell involves the production of new substances in one hand and breakdown of some substances on the other. In each tiny mass of protoplasm both these functions are carried out effectively and smoothly through a number of chemical reactions. The speed at which these chemical reactions occur is really amazing. All these activities involve the working of different biological catalysts called enzymes. The most interesting features of these chemial reactions are—(1) *existence of a "feedback" mechanism* and (2) *slow production of energy.*

Protein is the most important fabric of the cell. Therefore, the synthesis of protein is the most essential function of cell. The DNA present in the chromosome acts as *template* or *cast.* The available raw materials attach in specific sequence of this cast and with the help of an enzyme *RNA-polymerase* they are linked into a polynucleotide chain. This results in the formation of a particular type of RNA, called *messenger RNA,* which carries the information from DNA. Messenger RNA separates from DNA and passes into the cytoplasm. Within the cytoplasm at the sites of the ribosomes a second kind of RNA (*ribosomal RNA*) holds the messenger RNA in extended condition. From the cytoplasm, a third kind of RNA (*transfer RNA*) collects amino acids and delivers them to the proper position on the messenger RNA. One kind of transfer RNA can collect only one type of amino acid. Therefore the number of transfer RNA corresponds to the number of available amino acids. Thus, different transfer RNAs deliver their amino acids on the specific sites along the entire length of the messenger RNA which remains stretched on the ribosomes. These amino acids unite in a sequence to form a particular protein.

During the process of breakdown, carbohydrates, fats and proteins are converted into *pyruvic acid.* Of course, the cell can use these components only when they are in the form of glucose, fatty acids, glycerols and amino acids respectively. The pyruvic acid enters into the mitochondria and a part of it is further converted into energy-rich molecules called *Adenosine triphosphate* (ATP). These ATP molecules are used in different parts of the cell, e.g. in the membrane, in the cytoplasm, etc., to perform different functions. When energy is required this stored ATP is broken down into ADP or *Adenosine diphosphate* and energy is released. The ADP may be further broken down into *Adenosine monophosphate* (AMP) and more energy is released.

When synthesis is more than the breakdown new substances are stored within

the body. This results into growth. The phase of growth is not unlimited, after certain period of growth the cell duplicates. Thus reproduction (a process of self-duplication) is also operative at the cellular level, where multiplication takes place by division.

A question may arise that when all the cells are made up of protoplasm and when all of them are working in the same plan, what is the reason of diversity among themselves? The answer is that the working of a cell depends upon the interaction of two systems—message from the DNA and environment. The different parts of the cell including enzymes are made up of proteins. The control of the synthesis of proteins depends upon the message from DNA. In different species this DNA code (particular arrangement of nucleotides which, in its turn specify particular amino acid sequence in the protein chain) varies, which results into the variation of forms. The same code alters slightly within the cells of same individual, resulting into the formation of diverse types of cells. The second important system is the environment which supplies the precursors from which fabrics are built up according to the instruction.

CELL—Number, Size and Shape. Number of cells in an organism varies. In some organisms, the body is made up of many cells (multicellular) while in others it is made up of single cell (unicellular). In a human body it is calculated that there are 10^{14} cells on an average. Number of cells increases up to certain period of life and such increase ceases afterwards. The cells in a multicellular body are of two types, *germ cell* and *somatic cell*. The cells which are only responsible for reproduction are called germ cells and the remaining cells are called somatic cells.

Similarly, shape and size of the cells also vary extensively (Fig. 4.16). Some multicellular forms (Rotifers) may be smaller in size than many unicellular forms, i.e., *Amoeba*, *Spirostomum*, etc. Whereas some single cells like the eggs of birds and reptiles are quite large. A nerve cell may attain a length of several meters. Red blood cells are only 5-8μ in diameter. Within an organism the cells rarely remain in round state. They are flattened (epithelial cells), may be spindle-shaped (muscle cells) or spider-shaped (nerve cells) etc. The size and shape of a cell are related to its function and are governed by four factors—(1) surface-volume ratio, (2) nucleo-cytoplasmic ratio, (3) rate of cellular activity, (4) cell associations.

(1) **Surface-volume Ratio.** The cell membrane separates the inner content from the outer environment. But this separation does not mean isolation. A number of substances pass in and out through the membrane. These substances are essential for the activities of the cell. The total surface area of a cell is just sufficient for its inner content. Any increase in the surface area produces manifold increase of the cell volume which upsets the balance. Thus the particular shape and size which a cell attains are determined by the ratio of surface area and inner volume.

(2) **Nucleo-cytoplasmic Ratio.** The cell functions by the co-ordinated activities of its different parts. Most important is the co-ordination between nucleus and cytoplasm. Nucleus produces certain substances which come into the cytoplasm and control its activities. The cytoplasmic area of a cell is just enough which a nucleus can control. If the cytoplasmic area is much extended, it will not be possible for the nucleus to control its activity. For this reason a cell never attains size where nucleo-cytoplasmic ratio is more than one-seventh to one-twelfth. In certain cases this difficulty is overcome by the presence of more than one nucleus in a large cell.

(3) **Rate of Cellular Activity.** Though all the cells of a living body are equally important, yet some cells are metabolically more active than the others. The more active cells are usually smaller and in them, the surface-volume ratio and nucleo-cytoplasmic ratio are in such a level that the cells can work more actively than the larger cells.

(4) **Cell Association.** The cell-to-cell attachment is important in multicellular forms which render some amount of rigidity. The degree of attachment plays an important role in determining the shape of the cell and their functional property.

It is evident that all the four factors stated above are interrelated and of these

the surface-volume ratio and nucleo-cytoplasmic relations play the most important role in determining the size, shape and also characteristics of the cell. But everything depends upon the functions which are to be carried out. In many cells the surface area is increased by various sorts of folding. Such increase has reduced the chance of the alteration of inner volume.

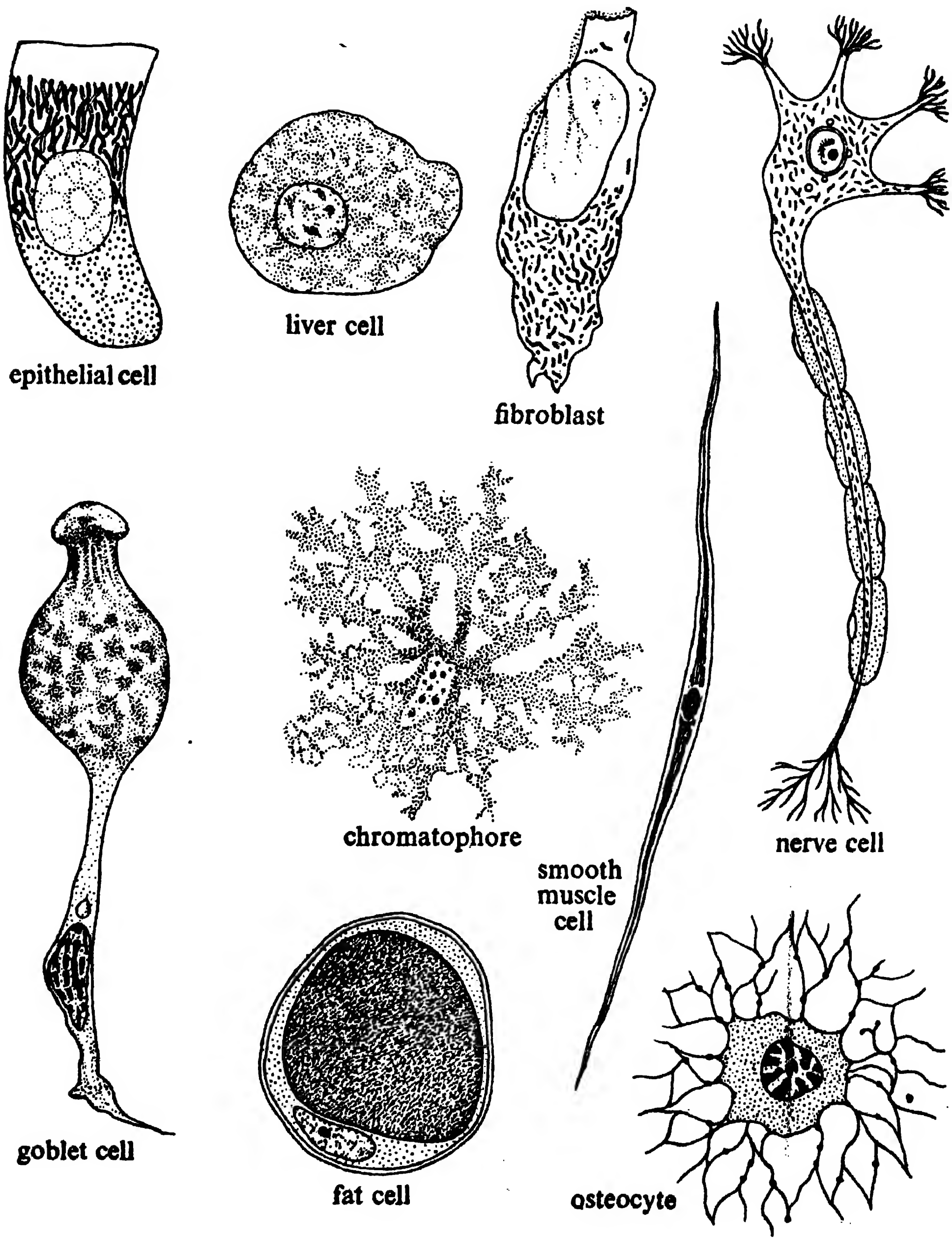


Fig. 4.16. A few examples of the cells having different shapes.

BIRTH AND GROWTH OF THE CELL CONCEPT

No single person can be pointed out to get the credit for present-day cell concept. It developed through more than three hundred years by the efforts of a number of workers in the different parts of the world. The most important aspect in the history of cell study is that it always progressed to solve a particular problem, but when the answer came, it merely unfolded some new problems to be investigated. The study of cell is therefore always regarded as the most dynamic and fascinating problem in biology.

The history of cell research may be divided distinctly into two parts— (I) findings of different structures in the cell and (II) attainment of generalisation.

I. FINDINGS OF DIFFERENT STRUCTURES IN THE CELL. The exploration of cell was always accompanied by the improvement and advancement of different tools and techniques. The study of architecture of living body started with unaided eye and came to a level beyond which it was not possible to advance. The need was met with the invention of microscope, an instrument which was meant for magnification. The quality of the microscope was gradually improved and in course of time phase-contrast, interference, and electron microscopes came, with only one purpose—to see and to know about the cells in more details. The methods of fixing and staining developed and attained such a level that today many specific compounds can be traced within a cell. Techniques were also developed to isolate different components of the cell and to analyse them. A short history of the progress is given below:

Bichat, Fernel and others studied the living body with the naked eye and very rightly came to a level beyond which nothing could be seen. Bichat examined tissues and concluded that different tissues have different architectures which depend upon their functions. Fernel studied muscle cells and inferred that muscle is made up of small muscles, which in turn is made up of smaller muscles. His conclusion was that it goes *ad infinitum.*

No further advancement was possible till 1665, when Robert Hooke, a well-known British scientist, described a thin slice of cork and other plant parts under a microscope. He described the presence of honeycomb-like structure and called each box a cell.

This was the beginning of the study of cell and many new discoveries were to follow. In the seventeenth century, Malpighi and Grew, independently examined cells in detail. But they too, like Hooke considered the cell wall as the all important parts and ignored its inner content. Corti (1772) and Fontana (1781) saw living substance in plant cells. Robert Brown (1883) identified the round body inside the cell as the nucleus. In 1885, Felix Dujardin named the jelly-like inner content of protozoans as *sarcode.* It was Purkinje who in 1840, used the word *protoplasm* to replace sarcode and in 1846 Van Mohl applied the term protoplasm to the plant cells. Rapid development of staining techniques led to the finding of other structures. Claude Bernard discovered mitochondria, Golgi described the structures of Golgi apparatus within the cell. The division of cell was noticed by Virchow (1859). Strasburger (1888) described chromosomes within the nucleus and it was found out by Flemming (1892) that division of a cell involves duplication of chromosomes. The discovery of the phenomena, that during the formation of gametes the chromosome number is halved and again after fertilisation the normal number is restored, drew the attention of embryologists to the problems of cytology.

The beginning of twentieth century was marked by an important advancement in cell studies when Morgan discovered the presence of trait-bearing bodies, called *Genes* in the chromosomes. This was soon followed by rapid emergence of studies. Brachet, Caspersson, Gomori and others using improved techniques traced the chemical nature of different structures within the cell. The use of ultra-centrifuge helped in the isolation and studies of different cell organelles. The techniques of cultivating cells *in vitro* was devised by Harrison and was improved by Carrol, Earl, Gay, Fell and others, which provided a new scope to study the living cells. The invention of electron microscope was successfully utilised by Porter, Fawcett, Novikoff, Sjostrand and others who added new dimensions

to our knowledge of cell structure. Today, along with the higher resolution of microscope many other tools like X-ray diffraction, chromotography, electrophoresis, spectrophotometry are adding new chapters to the study of cell.

II. **ATTAINMENT OF GENERALISATION.** The cells are always subject of study for having certain clues about the mysteries of living body. This study started to find out the ultimate architecture of living body. The trend showed by Vesalius was followed by Bichat and Fernel, who came down to a limit beyond which nothing is visible to the naked eye. The need to see better led to the discovery of microscope and it was left to Robert Hooke to confirm the assumption that in the living body there are minute compartments called cells.

While new facts were being discovered about cells in many organisms, Schleiden and Schwann in 1839 advanced what is known as the **cell theory** which states:

1. Animals and plants are made up of cells which are units of structure and function.
2. The cells have independent lives within higher forms of life.
3. New cells arise by a process resembling crystal formation.

This generalisation was an important step towards the progress of biology. But speakers in the centenary celebration of cell theory in 1939, like Conklin, Karling and others severely criticised Schleiden and Schwann for not giving due credit to their predecessors like Dutrochet of France who had clearly stated that cells are the units of living body and they possess independent life. Moreover, the third generalisation in the cell theory that new cells arise by a process similar to crystal formation, was found wrong by Virchow, who clearly demonstrated that cells always come from pre-existing cells. In spite of this criticism it must be said that the credit should be given to the proposers of the cell theory for being able to attract the attention of the biologists of their time and the impact was great. Virchow's enunciation provided a solid basis to the cell theory which still remains as one of the landmarks of modern biology. Later in 1861, Max Schultze of Germany observed that protoplasm is fundamentally similar in all animal and plant cells. The protoplasmic theory of Schultze was confirmed by T. H. Huxley and the concept of universality of protoplasm as the "physical basis of life" was another important generalisation of biology.

Once this was established, it was thought that chemical analysis of protoplasm will provide an answer to the question of mysteries of life. Numerous facts were known, but the final answer remained far away. The concept of common physical basis raised a number of questions—if protoplasm is same in all animal and plant cells what is the reason of this worldwide diversity? How was it attained through evolution? How do characters go from one generation to the other?

The beginning of twentieth century saw the coming of another important discovery when Morgan proved experimentally that chromosomes in the nucleus are the hereditary vehicles. Once this was known, extensive search continued to understand the working of nucleus and its relation with cytoplasm. From that moment, the study of cell joined the study of development and heredity.

At the present moment we know many details about cell. This knowledge has accumulated from the joint enterprises of physics, chemistry and biology. We know that DNA is the key chemical substance which serves as the basis of heredity. It controls, through RNA, the protein synthesis in cytoplasm but even today our knowledge about the nucleo-cytoplasmic interactions is incomplete. The cell as the unit of structure and function in all living organisms provides the underlying basis of unity in the great diversities of the living. We have this important generalisation today that "life is an uninterrupted succession of cells. Growth, development, inheritance, evolution, disease, aging and death are ... ... varied aspects of cell behaviour." But we are still far from complete understanding of the mechanism behind it.

CELL IN DIVISION

Self-duplication is the most important characteristic of the living substance. The cell carries the function by a process called, cell division. 'Multiplication by division' is a universal feature of life and it shows that cells always come from some

pre-existing cells which serves as the basis of the continuity of life. There are three types of cell division—(I) Mitosis, (II) Meiosis and (III) Amitosis, each of which will be discussed separately.

I. MITOSIS

The word mitosis means the division of the nucleus, but it is used to describe a process of cell division which involves both nucleus and cytoplasm. During mitosis, a cell divides into two daughter cells. The production of two cells is the attainment of a climax of extensive series of preparatory events which are blended into one another.

A. FUNCTIONS OF MITOSIS

1. Many single-celled organisms multiply through mitosis. This is the mode of reproduction in case of them.
2. Multicellular forms attain adult stage by this type of cell division.
3. This type of division meets normal wear and tear of the individual.
4. It occurs during wound healing and regeneration of lost parts.

B. FACTORS CONTROLLING MITOSIS

It is not known what stimulates mitosis. A number of chemical and physical agents are known which either promote or inhibit mitosis, but their mode of action is not clearly understood. The entire phenomenon depends upon a number of factors which may be grouped into two categories.

1. CONDITION OF CELLULAR METABOLISM. Cell division involves duplication of cell substance, therefore, the event depends upon the metabolic process of the cell for raw materials and energy. Any disturbance in the metabolic pathways of cell will inhibit the metabolic activity.

2. CONDITION OF CELLULAR SPECIALISATION. Cells which are specialised for a particular function, tend to lose their ability to divide, whereas unspecialised cells may divide at regular intervals.

C. EVENTS OF MITOSIS

The entire process of mitosis may be separated into two broad categories, namely, chemical events and physical events. The chemical events, which are responsible for duplication, start long before the appearance of physical events which involve equal distribution of cellular materials.

1. **Chemical Events.** Within the nucleus of a cell, which is destined to divide, the chromosomes synthesise more DNA and it has been shown that such a cell doubles its DNA content. During this process the genes which are present on the chromosome duplicate. The duplication of all the genes results into the doubling of the chromosome but the line of division remains invisible. The chemical events in mitosis have been extensively studied by Taylor at chromosomal level and by Messelson and Stahl at molecular level. Their study revealed that the molecular doubling of genetic material has its parallel in the doubling of chromosomes at the cytological level. There is considerable lapse of time between the end of the chemical events and the beginning of the physical events. It is believed that some other biochemical changes occur at the stage of interphase (Fig. 4.17A) which are necessary for the physical events.

2. **Physical Events.** The entire visible process of mitosis may be divided into four stages. These are Prophase, Metaphase, Anaphase and Telophase (Fig. 4.17) and are followed by cytokinesis. It is not that during division the cell stops for a while at each stage, on the contrary, the entire process is a dynamic and continuous one. Time required for the completion of a particular stage or of the entire process varies in different types of cells and also depends on different physical and chemical factors.

a. Prophase

During this stage changes occur both within the nucleus and in cytoplasm. Within the nucleus the nucleolus disappears at the end of prophase and the chromosomes become visible. The visibility is due to the condensation of chromatin fibres from slender thread-like appearance to stout chromosomes (Fig. 4.17B–C). In the beginning of prophase the outer surface of the chromosome remains irregular but at the end of prophase it becomes smooth. Each chromosome, which is already duplicated, is made up of two closely set pairs, the *chromatids*. The two chromatids are united together at a region which does not take chromosomal stains. The region of attachment is called *centromere* or *kinetochore*. The position of the centromere on the chromosome varies but for a

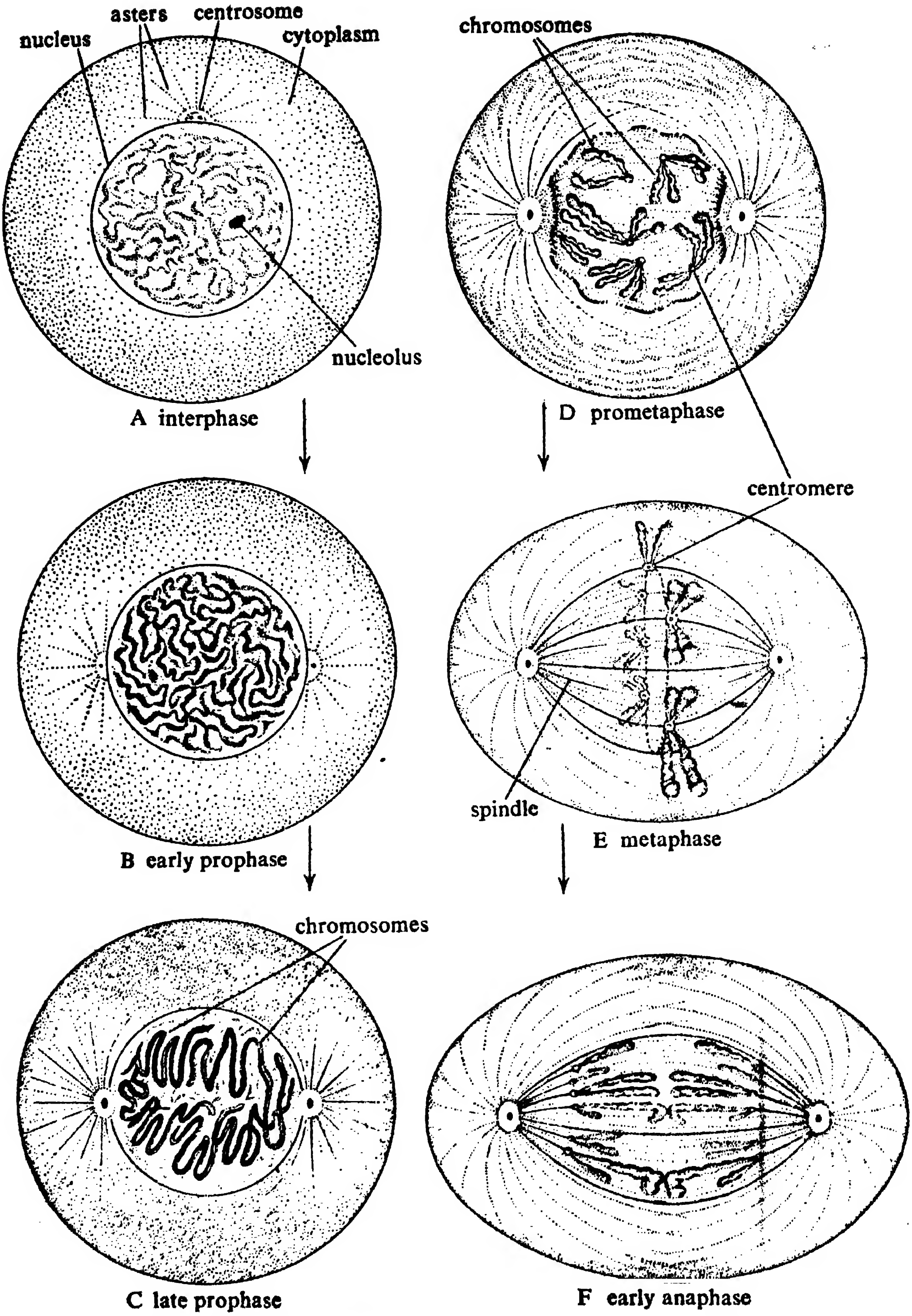


Fig. 4.17. (A–F)—Stages of mitosis—A. Interphase, B. Early prophase, C. Late prophase, (D) Prometaphase, (E) Metaphase, (F) Early anaphase. The circle drawn in Fig. E to indicate equatorial plane is imaginary. It never appears during cell division.

particular chromosome the position is constant. When centromere is diffused along the entire length of chromosome it is called *polycentric chromosome*. When the centromere is present at the centre of the chromosome, it is called a *metacentric chromosome* and when the centromere is placed at one end of the chromosome it is regarded as an *acrocentric chromosome*. In another form of chromosome the centromere is absolutely terminal, it is called *telocentric chromosome*. In the cytoplasm,

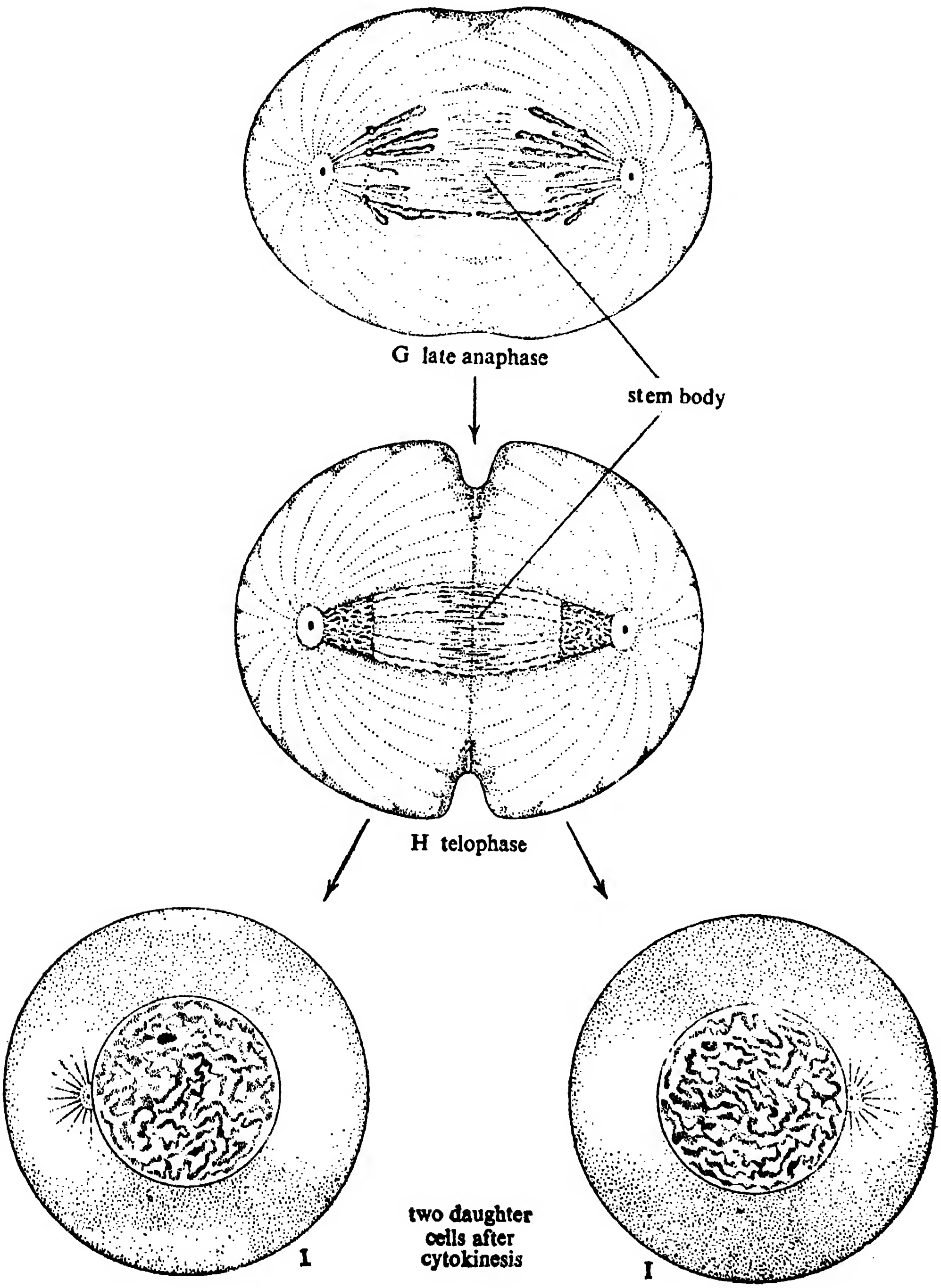


Fig. 4.17. (G–I)—Diagrammatic representation of mitotic stages (contd.). (G) Late anaphase, (H) Telophase, (I) Two daughter cells after cytokinesis.

with the commencement of prophase stage the centrosome containing the centriole splits into two and the two parts move away from each other. When they reach two opposite poles a portion of cytoplasm forms a gel around them and encircles it as radiating fibres. This body is now called *aster*. Number of gelatinous fibres appear in the cytoplasm. They are called the spindle fibres. These fibres connect the two centrioles. The spindle fibres are made up of protein and RNA and they can be isolated from the cell. The arrangement of spindle varies widely in different cells. Three sets of fibres are generally visible. One set connects the two polar centrioles; the second set connects the centromeres with the centrioles and the third set, in between the daughter chromosomes. These inter-chromosomal fibres push the chromosomes during their journey to the poles.

At the end of prophase, the nuclear membrane disappears and the chromosomes are shifted mechanically and come towards the equator of the spindle. The phase of spindle formation and movement of chromosomes to the centre is also termed as *prometaphase* (Fig. 4.17D).

b. Metaphase

It is a brief phase during which very little visible changes occur. Arrangements along the equator depend upon the nature of chromosomes, i.e. metacentric chromosomes become V-shaped and acrocentric chromosomes remain straight or L-shaped (Fig. 4.17E).

c. Anaphase

This phase involves the journey of chromatids to the opposite poles. It starts with the movement of daughter centromeres. Each daughter centromere while moving to the pole drags one chromatid from the other. At the same time the central spindle between the two chromatids elongates to form a pack of filiform structures called *stem body*. Thus anaphase stage is the result of two processes, movement of centromeres and elongation of spindle, both of which vary in different organisms. The indication of cytoplasmic separation begins from this stage (Fig. 4.17F–G).

d. Telophase

The daughter chromosomes after reaching the poles, lose their smooth texture and start to de-condense. The chromosomes form a loose network around which a new nuclear membrane is formed. It is believed that the nuclear membrane arises from the endoplasmic reticulum. A nucleolus reappears in each of the daughter nuclei (Fig. 4.17H–I).

e. Cytokinesis

During the end of telophase a furrow is formed in the cell membrane along the equator. This furrow deepens and considerable movement of cytoplasm takes place. Then all on a sudden the cell is pinched into two along the furrow in the equator and the cytoplasmic turbulence ceases (Fig. 4.17I).

II. MEIOSIS

Meiosis is a special type of cell division which occurs in sexually reproducing organisms. In all organisms the chromosomes remain in pairs. The organisms reproducing asexually multiply by mitosis. Thus, there exists no chance of alteration of chromosome number. On the contrary, sexual reproduction demands contribution from two individuals. Thus there lies a risk of chromosomal disbalance. The process of meiosis helps to avert this probability by reducing the number of chromosomes to half. It may happen after gametic union (as in sporozoa) or before fertilisation (in all higher organisms). In higher organisms, therefore, mitosis occurs in both somatic and germ cells but meiosis takes place in the germ cells alone and only during the formation of gametes.

A. FUNCTIONS OF MEIOSIS

1. It checks the disbalance of chromosome number (by reducing the chromosome number to half in the gametes, which after union restores the specific number).
2. It produces random assortment of chromosomes, which results into the production of a large number of variations.

B. STEPS OF MEIOSIS

Meiosis involves two divisions of the cell but one division of the chromosome. Thus the entire process of meiosis may be splitted into—(1) First meiotic division and (2) Second meiotic division.

1. First Meiotic Division. This involves all the phases of mitosis—Prophase, Prometaphase, Metaphase, Anaphase, Telophase and Cytokinesis (Fig. 4.18), but the incidents during the events are different.

a. Prophase

It is the longest phase in the first meiotic division and much longer than mitotic prophase. It can be subdivided into the following stages: (*i*) *Leptotene* or *Leptonema*, (*ii*) *Zygotene* or *Zygonema*, (*iii*) *Pachytene* or *Pachynema*, (*iv*) *Diplotene* or *Diplonema*, and (*v*) *Diakinesis*.

(*i*) **Leptotene.** It is a short stage during which chromosomes become elongated and

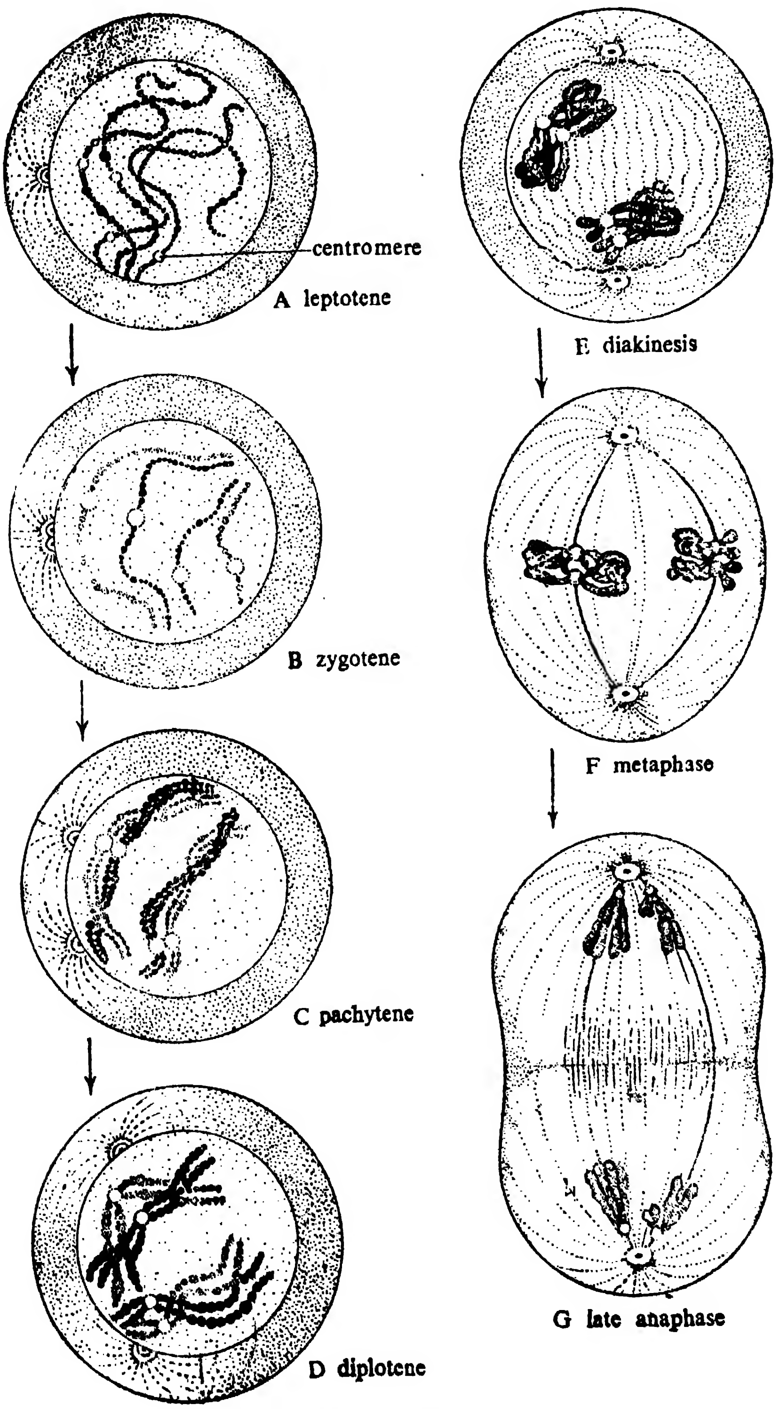


Fig. 4.18. Meiosis—Stages of first meiotic division.

slender (Fig. 4.18A). Whether the leptotene chromosomes are split to form chromatids or not, is still a matter of dispute.

(*ii*) **Zygotene.** At this stage an important event called *synapsis* or pairing occurs. During this event, the homologous chromosomes pair and their homologous regions come in close approximation with each other throughout their length. The pairing begins from the end away from the centromere and gradually extends along the entire length of the chromosome (Fig. 4.18B) and it ends with the pairing of the centromeres. The pairing of homologous chromosomes results into the formation of bivalents.

(*iii*) **Pachytene.** At this stage (Fig. 4.18C) the bivalents condense and each chromosome of the bivalent divides into two strands. Thus at the end of pachytene, the bivalent looks like a four-stranded structure, all the strands being closely set together.

(*iv*) **Diplotene.** (Fig. 4.18D). The force that kept the bivalents together ceases to act at this stage and the members of the bivalent separate except at certain points where two strands, one from each homologous chromosome, unite together to form Xs (Fig. 4.20). These points are called *chiasmata*. The number of chiasma in a bivalent varies from 1–12. Two hypotheses are well known to explain the formation of chiasma.

According to the *Classical hypothesis*, on one side two paternal and two maternal chromatids are paired and on the other side a paternal chromatid pairs with a maternal and a maternal chromatid pairs with a paternal one. It means that formation of a chiasma may or may not give rise to a crossing-over.

According to *Chiasma type hypothesis*, two strands in a four-stranded bivalent, break and unite diagonally in a X-shaped fashion to form chiasma. It means that crossing-over precedes the formation of chiasma.

Why do the chromatids break and then rejoin? Wherefrom comes the motive force of chiasma formation? Why both the chromatids from maternal and paternal chromosome split at a particular region? These are a few of the many unanswered questions about the chiasma formation.

But this is known that occurrence of one chiasma prevents the formation of another chiasma at the nearby region. This phenomenon is called *chiasma interference*. At the end of diplotene, the chromosomes thicken and become short. In some forms, the chiasma slips and comes to the terminal end of chromosomes. This is called *terminalisation*.

(*v*) **Diakinesis.** Bivalents become short, thick and darkly stained. These bivalents move towards the inner side of the nucleus (Fig. 4.18E).

b. Metaphase

At the end of prophase, nuclear membrane disappears and the spindle is formed. The bivalents remain attached to the spindle fibres by its two centromeres. During their arrangement in the equator, one centromere remains above and the other remains below the equator. It may be mentioned here that the centromere during mitosis remains perfectly on the equator. The chromosomes become much condensed and gain a smooth appearance. The gap between two centromeres is dependent upon the position of chiasma (Fig. 4.18F).

c. Anaphase

Each member of the bivalent chromosomes begins to move towards the pole (Fig. 4.18G). It is dragged by the centromere with which the fibres of the spindle are connected. The behaviour of chromosomes is the same as in mitosis. Only difference is that during mitosis, a half centromere and one chromatid migrates while here an entire chromosome having two chromatids and an intact centromere does the same behaviour.

The movement ends the pairing of the bivalent which causes the chiasmata to slip off from the terminal end. It must be remembered that chromosomes which separate during anaphase are not the same which appeared during zygotene to form the bivalent. Due to chiasma formation and crossing-over, many parts of it are reorganised.

d. Telophase

This phase resembles that of mitosis. Only difference is the orientation of chromatids. Two chromatids of each chromosome are arranged either like L or V. A narrow stem body persists between the nuclei at the two poles.

CYTOKINESIS

The occurrence of cytoplasmic division may or may not follow the nuclear separation. In some cases a resting stage or interphase or interkinesis appears, while in many instances the telophase nuclei pass directly into the prophase stage of second meiotic division.

2. SECOND MEIOTIC DIVISION (Fig. 4.19). The process is almost similar to the normal mitosis.

(*a*) *Prophase.* It is a brief stage and is similar to the mitotic prophase. No complication occurs as in the first meiotic division (Fig. 4.19A_1,A_2).

(*b*) *Prometaphase and metaphase.* Spindles are organised very quickly and the chromosomes which are reduced to half are seen to possess widely separated chromatids with attachment only with the centromere.

(*c*) *Anaphase.* Centromere of the chromosome divides and two halves are drawn towards the opposite poles (Fig. 4.19B_1,B_2). Each half of centromere carries with it the already separated chromatid.

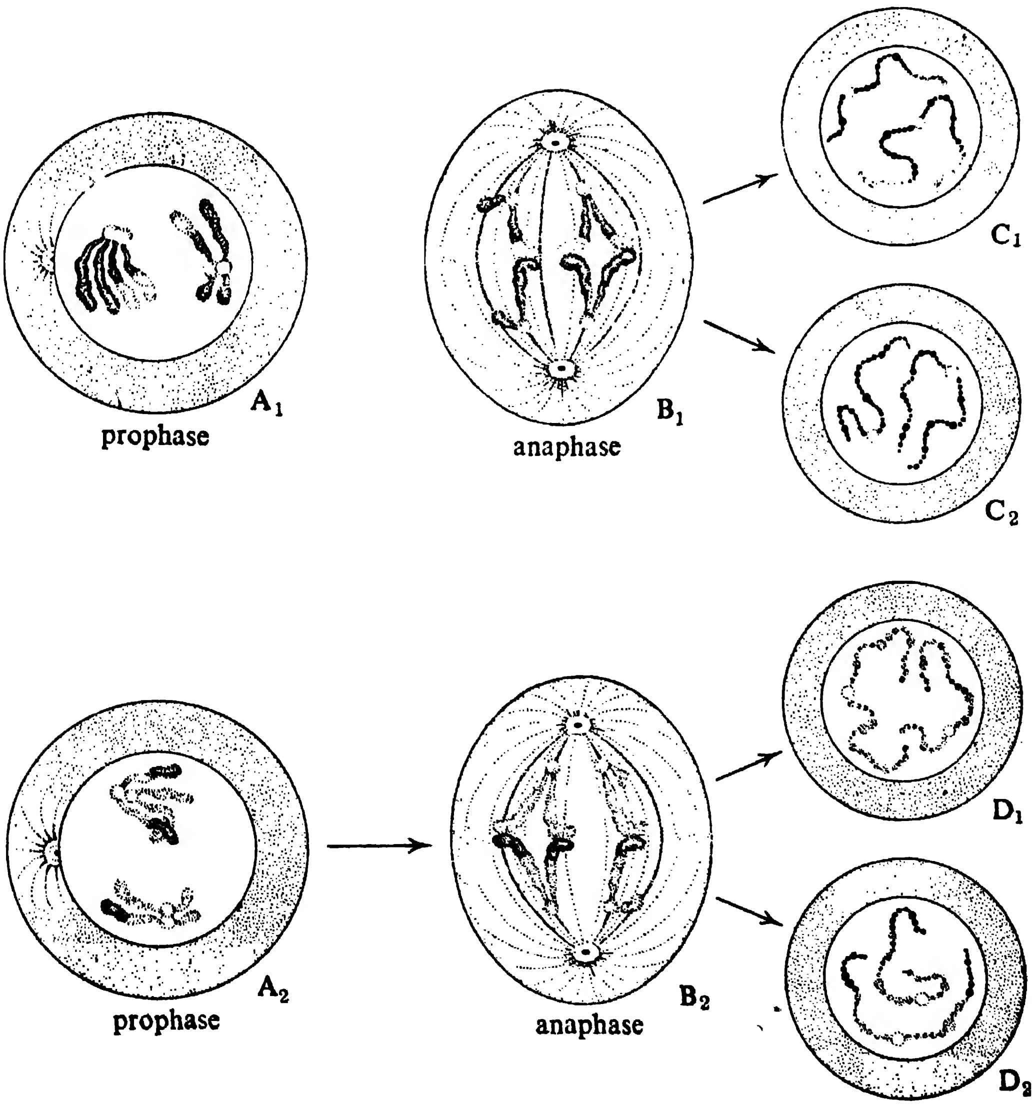


Fig. 4.19. Meiosis (contd.)—Stages of second meiotic division.

(*d*) *Telophase.* The process is same as that of mitotic telophase, with the only difference that the telophase nuclei here contain only half the number of chromosomes.

(*e*) *Cytokinesis.* It is same as in mitosis and results into two daughter cells. Thus four cells are produced, each with half the number of chromosomes of the mother cell (Fig. 4.19 C_1, C_2, D_1, D_2).

Significance of meiosis. It has already been discussed that in higher organisms meiosis occurs in the cell which forms the gametes. In the formation of both male and female gametes from one gametocyte, four daughter cells are produced with haploid number of chromosomes. In the males, all the daughter cells become functional gametes or sperm cells. But in females, the unequal cytokinesis results into the formation of one large cell and three small cells. Each of them contains haploid number of chromosomes, but only the large cell becomes the functional gamete and the other three, called the polar bodies or polocytes, become abortive. Another fascinating aspect of meiosis is that it begins at *the very early life in the individual* but remains arrested for a considerably long time in the prophase state. In males the completion depends upon the attainment of sexual maturity. In the female, the completion of the division comes only shortly before or after fertilisation. The process of meiosis not only reduces the chromosome number to half for the purpose of reproduction but also by random distribution of paternal and maternal chromosomes and by crossing-over through chiasma (Fig. 4.20), it produces gametes, none of which are exactly alike. Thus, a large number of variations result, which have got great significance in evolution.

Fig. 4.20. Mechanism of chiasma formation and crossing-over.

III. AMITOSIS

For a long time it was known that in several instances the nucleus divides without the disappearance of nuclear membrane and the formation of spindle apparatus (Fig. 4.21). Such direct division of nucleus is known as amitosis. The application of improved techniques has shown that in cells dividing amitotically, probably there exists some intranuclear mechanism

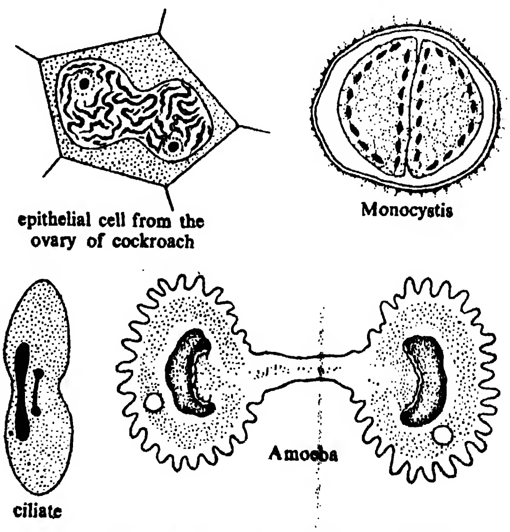


Fig. 4.21. Different types of amitotic division.

for equal distribution of chromosomes. The division in amoeba, which was regarded to be amitotic in nature, is now established to be mitotic division.

TABLE 2

Comparative account of mitosis and meiosis

POINTS OF DISCUSSION	MITOSIS	MEIOSIS
1. Nuclear division and chromosome duplication	Mitosis involves one nuclear division. It is the chief process of reproduction in many unicellular organisms. Each division ensures duplication of chromosomes.	Nuclear division occurs twice in close succession but the chromosomes are duplicated once only.
2. Chromosome number	As a consequence of mitosis daughter nuclei maintain the same number of chrosomes as before the division (diploid chromosome set).	Meiotic division results into four daughter cells. The number of chromosomes in each of these cells are reduced to half (haploid chromosome set).
3. Occurrence in the body	Mitosis is the general mode of division of body cells. The resultant cells are similar.	Meiosis occurs in the specialised tissues like testis and ovary resulting into sperms and ova (reproductive cells) respectively in sexually reproducing organisms. The resultant cells may be dissimilar (as in the case of oogenesis).
4. Purpose of division	The general purpose of mitotic division is the material increase of cell number.	Meiosis is a significant condition for sexual reproduction. The haploid set of chromosomes in gametes fuses to form the diploid zygote and thus the usual chromosome number of the species is maintained.
5. Time of DNA synthesis	Synthesis of DNA occurs strictly in the interphase. In addition, synthesis must occur in every interphase.	Synthesis may extend even up to early prophase (I). Transient interphase after the first meiotic division is devoid of synthetic phase.
6. Stages	A. *Prophase* Prophase is the longest phase. Chromosomes become visible and in due time each appears as paired threads of chromatids. Nuclear membrane disappears and the spindles appear. Usually there occurs no bivalent, chiasma and crossing-over though there are recorded	A. *Prophase* (1st) This is also the longest phase as in mitosis but is much more complicated. The entire phase has been subdivided into the following: (*i*) Leptotene or Leptonema, (*ii*) Zygotene or Zygonema, (*iii*) Pachytene or Pachynema, (*iv*) Diplotene or Diplonema and (*v*) Diakinesis.

TABLE 2 (contd.)

POINTS OF DISCUSSION	MITOSIS	MEIOSIS
6. Stages (contd.)	instances of somatic crossing-over with the pairing of chromosomes. But formation of chiasma is lacking in those cases.	The characteristic events are: Chromosomes become discrete, visible and oriented in a polarised way. The homologous chromosomes become entwined. These paired chromosomes are now termed bivalents. Now each chromosome in the bivalent splits into two chromatids. This is followed by breaking and rejoining of chromatid segments resulting into exchange of genetic material between the homologous chromosomes (crossing-over). This is accompanied by chiasma formation. Chiasma is the cytological equivalent of crossing-over. The bivalents now begin to orient themselves on the spindle. Each has two centromeres. Interchange of chromosomal material involving genetic exchange renders evolution its dynamicity.
	B. *Metaphase* Chromosomes become most distinct and take the equatorial position. Each attaches to the spindle fibre at the centromeric region.	B. *Metaphase* (1st) Centromeres get attached with spindle fibres. Bivalents orient themselves at the equator in such a way that each of the homologous chromosomes can move to the reverse pole.
	C. *Anaphase* Centromere divides. Chromosomes are pulled lengthwise to the opposite poles and since each chromosomal material consists of two chromatids, one chromatid of each chromosome moves towards one pole of the spindle.	C. *Anaphase* (1st) Characteristic feature of meiotic anaphase (I) is that it results in the segregation of homologous chromosomes to the opposite poles. Each of these parting members of the homologous set (with its new genetic make-up resulting from crossing-over) may eventually participate in the genetic constitution of two individuals of the next generation through fertilisation of the resultant sex cells. The phenomenon has definite importance from the point of view of evolution.

TABLE 2 (contd.)

POINTS OF DISCUSSION	MITOSIS	MEIOSIS
6. Stages (contd.)	D. *Telephase* Chromosomes start reassuming the thread-like state by the gradual process of uncoiling. Spindles disintegrate. Daughter nuclei (and cells after cytokinesis) result.	D. *Telophase* (1st) Two daughter nuclei (and eventually cells) are formed in the same way or the two sets of chromosomes may enter directly into the second meiotic division.
7. Duration	Cells pass through the interphase state until further division occurs in the same manner. Duration of the entire mitotic division ranges from 30 minutes to several hours.	Duration of the entire meiotic division is usually much longer in comparison to that of mitosis. The second meiotic division involves two daughter nuclei or cells. The characteristics are: (*i*) Centromere splits so that at anaphase (II) the chromatids can move to the two poles. (*ii*) At telephase (II) nuclear membrane forms around each mass of chromosomal materials. Four nuclei (and cells after cytokinesis) result, each containing only one set of homologous chromosomes.

SUMMARY

(*i*) The cell is the unit of a living body. It contains—(*a*) plasmalemma, (*b*) cytoplasm and (*c*) nucleus.

(*ii*) The plasmalemma acts as limiting membrane, the cytoplasm forms the ground substance and retains various organelles, i.e. centrosome, Golgi bodies, mitochondria, endoplasmic reticulum, lysosomes and ribosomes.

(*iii*) The nucleus is the controlling centre of the cell and contains nuclear membrane, nuclear sap, nucleolus and chromatin bodies.

(*iv*) The cell function involves synthesis (anabolism) and breakdown (katabolism). The anabolism exceeds katabolism in the young cell and growth takes place. After certain period of growth the cell divides by duplication, this is mitosis.

(*v*) Another type of cell division is seen during the formation of reproductive cells. This is meiosis.

(*vi*) The third type of cell division, amitosis, is also seen in some cases.

(*vii*) Mitosis results in duplication of chromosomes but meiosis reduces the number and also renews the structure of chromosomes.

CHAPTER 5

Tissues

Cells are the units of living body. In the body of man there are approximately 10^{14} cells, all of them have been produced from a single cell, the zygote. It has been calculated by Gamow that nearly 50 mitotic divisions are necessary to produce such a huge quantity of cells (Fig. 5.1). Development does not mean quantitative increase only, but also it leads to qualitative changes. From a single cell develops a

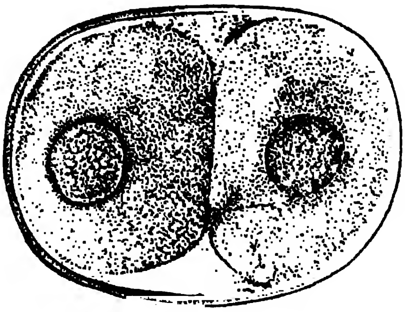


Fig. 5.1. Human zygote at two cell stage. Fifty divisions are necessary to produce an adult human body.

pack of homogeneous cells which ultimately form heterogeneous groups. The attainment of this diversity within a single organism results into the division of labour. In order to carry out a particular function, certain cells attain certain common morphological and functional features—and that collection of cells with similar structure and function is called a tissue.

Four different kinds of tissues are seen in the animals—*Epithelial*, *Connective*, *Muscular* and *Nervous*. Each group includes several types, which will be discussed separately.

1. **EPITHELIAL TISSUES.** The cells taking part in this type of tissue have a regular, well-defined shape and scanty intercellular substance. They are usually in contact with one another on a definite basement membrane. The epithelial cells either form compact groups or form a continuous lining on all external or internal free surfaces. These tissues are without vascularisation but contain nerve fibres and migratory cells. When epithelial tissue is made up of a single layer of cells, it is called *simple epithelial tissue* and when it is many-layered it is called *compound* or *stratified epithelial tissue*. According to the shape of the cells (Fig. 5.2) which are present near the surface, the epithelial tissue may be (A) *Squamous*—These are tile-like flat cells. The simple squamous epithelium is seen in peritoneum of frog, alveoli of lungs and endothelium of blood vessels. The stratified squamous epithelium is found in epidermis, wall of oesophagus, cornea and a part of female urethra. (B) *Cuboidal*—Cube-like cells with polygonal outer surface, e.g. lining of thyroid vesicles and kidney tubules. (C) *Prismatic* or *Columnar*—The simple columnar tissues include tall cells with distinct elongated nucleus, e.g. lining of alimentary canal. The stratified columnar is seen in the pharynx, epiglottis as a pack of cells in which inner cells are fusiform and outer cells are tall and prismatic in appearance.

The columnar epithelium may be (1) *Ciliated*—Possessing short vibratile cilia for removing fluid, mucous and other materials, e.g. lining of nasal tube, lining of bronchial tube and lining of Fallopian tube. (2) *Flagellated*—Each cell possesses a single flagellum, e.g. flagellated cells in the endoderm of hydra. (3) *Stereo-ciliated*—Here the cells are with one or two immobile cilia at their free end, e.g. lining of nostril, tongue and internal ear. These are sensory cells for receiving different

stimuli, i.e. smell, taste and hearing. (4) *Brush border*—Free end of the cells has brush-like appearance. These are responsible for absorption, e.g. lining of the intestine. All the above mentioned epithelial tissues are included in this group. These epithelia carry following functions:

(*a*) Absorption, e.g. Brush-border columnar.

(*b*) Diffusion, e.g. squamous.

(*c*) Secretion, e.g. cubical.

(*d*) Protection, e.g. squamous, ciliated columnar.

(*e*) Sensory, e.g. stereo-ciliated.

either scattered or in a group within other epithelial cells or may be variedly organised to form *glands*. The glands are chiefly either *tubular* or *saccular*. The tubular glands may be *simple* (intestinal gland), *branched* (lacrimal gland) and *coiled* (sweat gland). The saccular glands are again *simple* (present in skin of toad,) *compound* (salivary gland) and *branched* (sebaceous gland). Some glandular epithelial cells give out only their product (*merocrine*), others throw their entire cell together with the content (*holocrine*), e.g. sebaceous gland. In the third type

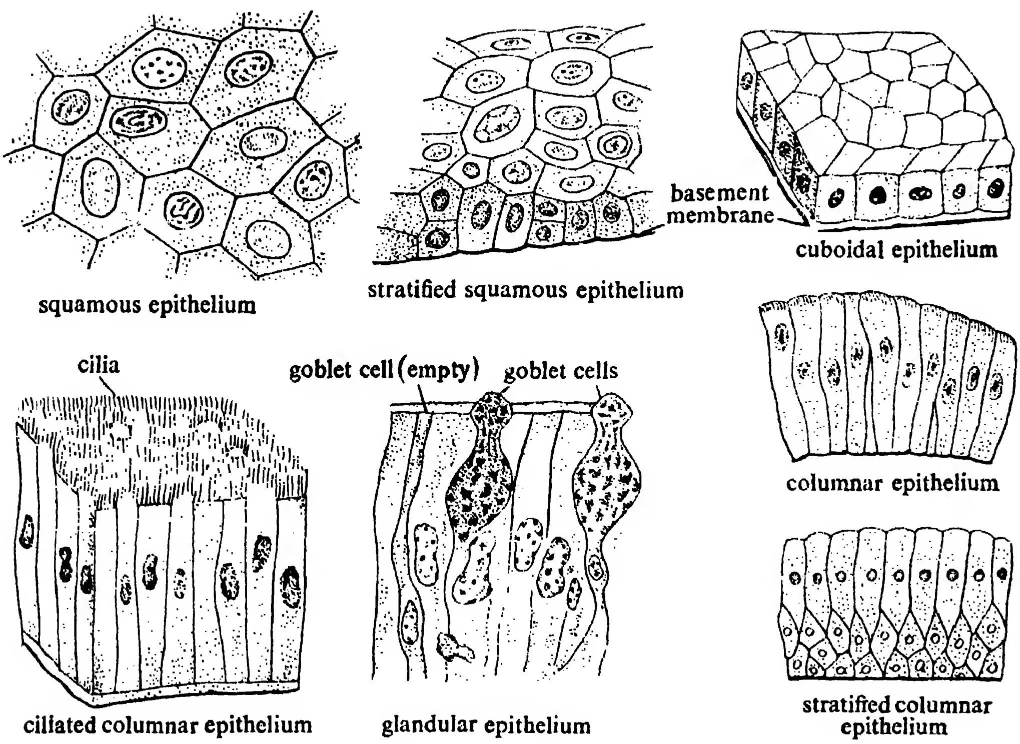


Fig. 5.2. Different types of epithelial tissues.

According to its function, the epithelial tissues may be (A) *Covering epithelium* and (B) *Glandular epithelium*.

A. COVERING EPITHELIUM. It includes the covering of external or internal surfaces.

B. GLANDULAR EPITHELIUM. It includes specialised epithelial tissues which have acquired either secretory or excretory properties. In general, the cells of the glandular epithelium possess large nuclei, prominent Golgi apparatus and the secretory products in the form of granules. The glandular epithelium may be present

(*apocrine*) only the free regions of the cells burst and the products are extruded out, e.g. mammary glands. Some glandular epithelium secretes through definite duct or tube (*exocrine glands*), while there are certain glandular epithelia which put their product directly into the blood stream (*endocrine glands*).

II. **CONNECTIVE TISSUE.** Connective tissues are characterised by groups of cells which remain embedded in a extracellular material called *matrix*. According to the nature of the matrix the connective tissues may be (A) *Connective*

tissue proper, (B) *Skeletal tissue* and (C) *Vascular tissue*.

A. CONNECTIVE TISSUE PROPER. These tissues are concerned with binding and packing of different parts.

Following tissues are included under this group: (*a*) *Mucous tissue*, (*b*) *Reticular tissue*, (*c*) *Areolar tissue*, (*d*) *Fibrous tissue* and (*e*) *Adipose tissue* (Fig. 5.3).

(*a*) MUCOUS TISSUE. These connective tissues are best seen in jelly fishes and in the eye of the vertebrates. It consists of a few branched cells and clear gelatinous ground substances called *matrix*. Two types of cells are seen in the matrix, namely *fibroblasts* which are responsible for the production of fibres and *matrix cells* for secreting the matrix. Two kinds of fibres are *yellow elastic fibres* as freely branched network and *white fibres* containing bundles of *collagen fibres*.

(*d*) FIBROUS TISSUE. These tissues are entirely made up of fibres and they form sheath over the *muscles*, *tendon* and *ligaments*. Tendons are responsible for connecting muscles with the bones or with other muscles. In tendons the fibres contain collagen and are arranged in parallel fashion. Ligaments connect different bones

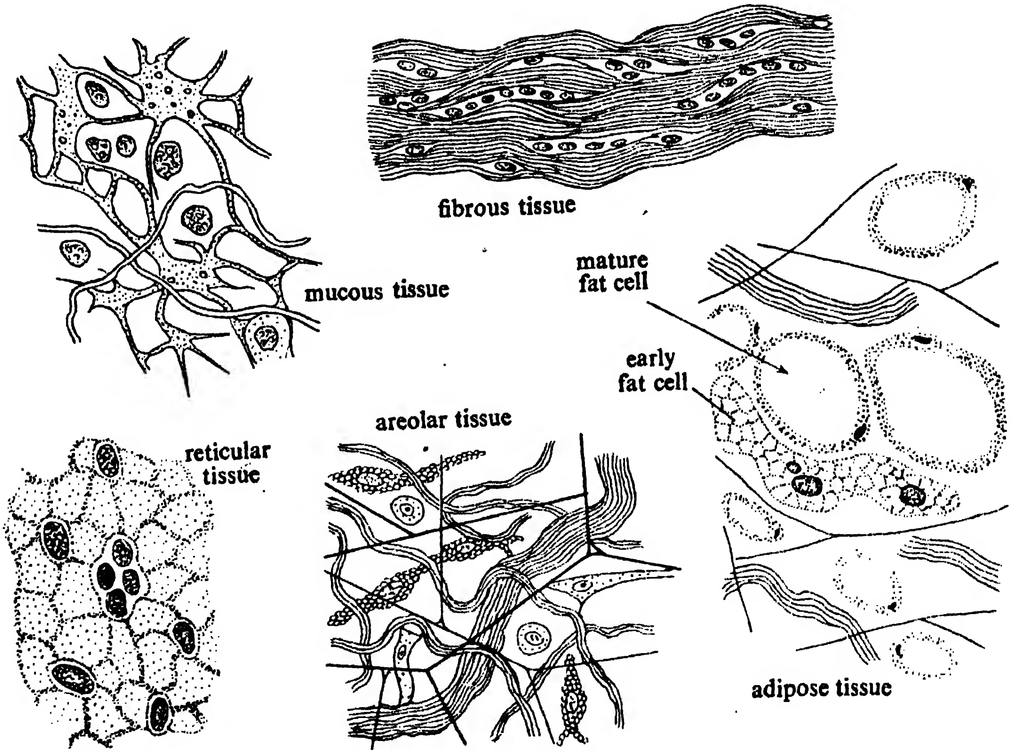


Fig. 5.3. Different types of connective tissue proper.

(*b*) RETICULAR TISSUE. It consists of a dense network of reticular fibres with free cells. The nature of the cell varies according to organ. This tissue forms the framework of various organs like lymph node, bone marrow and liver.

(*c*) AREOLAR TISSUE. It serves as a packing layer beneath the skin and fills up the gaps between different organs. It consists of a jelly-like matrix in which different cells and fibres are embedded.

and also bones with cartilages. Its fibres contain collagen and in addition, another protein called *elastin*, which permits the stretching and recoiling.

(*e*) ADIPOSE TISSUE. This tissue contains cells which are primarily responsible for carrying reserve fats. This layer beneath the skin serves as insulating layer. As a covering around important organs, it works as a cushion to protect these organs from mechanical injury.

B. SKELETAL TISSUE. Two types of skeletal tissues are known (*a*) *Cartilage* and (*b*) *Bone* (Fig. 5.4).

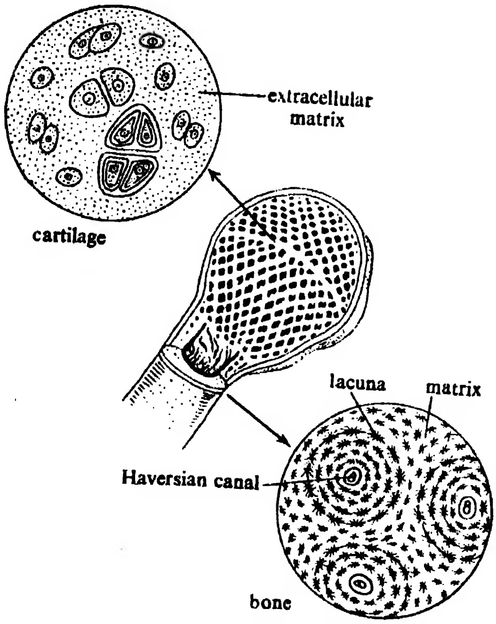


Fig. 5.4. Examples of skeletal tissue.

(*a*) CARTILAGE. This tissue is rigid and at the same time elastic. It is capable of enduring mechanical stress. It consists of a ground substance which contains a protein and polysaccharide mixture called *chondrin*. Within this matrix are suspended the cartilage cells or *chondrioblasts*, which secrete the matrix. The cells are enclosed in spaces within the matrix called *lacunae* where they multiply and remain in groups of two to four. A coat of areolar tissue called *perichondrium*, surrounds the cartilage.

Depending on the nature of the matrix the cartilages are divided into two main categories: (*i*) **hyaline** and (*ii*) **elastic cartilages.** The hyaline cartilage has a homogeneous and transparent matrix. It can be seen in larynx, trachea and suprascapula. The matrix of elastic cartilage bears yellow elastic fibres (seen in epiglottis) or with parallel collagenous fibres (seen in between the vertebrae).

(*b*) BONE. It is a hard connective tissue which is responsible for forming the skeletal framework of the body. It is rigid and can endure great mechanical strain. Each bone consists of a central cavity which contains *bone marrow*. The cavity is bounded by concentric layers called *bony lamellae*. Through the lamellae pass numerous smaller channels from the narrow cavity; these are called *Haversian canals*. These canals are also lined by concentric rings of lamellae. Each lamella is made up of a matrix in which bone cells are arranged within smaller spaces called *lacunae*. The lacunae are interconnected by finer *canaliculi*. The matrix of bone is made up of protein fibres and mineral deposits like calcium phosphate, magnesium carbonate and fluorides. The bone cells are known as *osteoblasts*, which are spider-shaped. These cells are interconnected by protoplasmic processes which pass through canaliculi. Externally the bone is enclosed by a fibrous sheath called *periosteum*, which takes the blood vessels within the cavity of bone marrow.

C. VASCULAR TISSUES. It includes *blood*, *lymph* and *bone marrow* (Fig. 5.5).

(*a*) **Blood.** This tissue not only connects different parts but also performs certain other important functions. It has a liquid matrix called *blood plasma* in which are suspended various *blood corpuscles*.

(1) **Blood plasma.** It is a pale yellow-coloured liquid in which various substances like food, waste products, hormones and gases remain in solution. It transports everything excepting oxygen in vertebrates and fat droplets. Within the body of invertebrate animals, the colouring pigments remain in the plasma, e.g. haemocyanin in prawn and haemoglobin in earthworm.

(2) **Blood corpuscles.** Only one type of corpuscle is seen in the invertebrates which are amoeboid in nature. But in vertebrates several types of corpuscles are seen, e.g. *Erythrocytes*, *Leucocytes* and *Thrombocytes*. These corpuscles are formed within the marrow. They have a limited span of life after which they are destroyed.

(*i*) **Erythrocytes.** Presence of red blood corpuscles (RBC) is peculiar to vertebrates excepting some invertebrate forms, e.g. *Glycera*, *Phoronis*, *Arca*, *Thyone*. The shape and size of erythrocytes differ in various groups of vertebrates but always the erythrocytes carry an iron-containing compound called *haemoglobin*. Haemoglobin is a complex molecule composed of a compound of *iron* and *globulin*. This compound can establish temporary affinity with oxygen and thus carries oxygen from respiratory organs to the different parts of

the body in the form of *oxyhaemoglobin.* Erythrocytes are nucleated in all the vertebrates excepting mammals, where it is non-nucleated in mature stage. They appear as oval discs in most vertebrates and appear to bulge out in the centre due to the presence of nucleus. But in mammals (except camels and llamas where the RBC are oval discs like non-mammalian forms) they are more or less circular in outline.

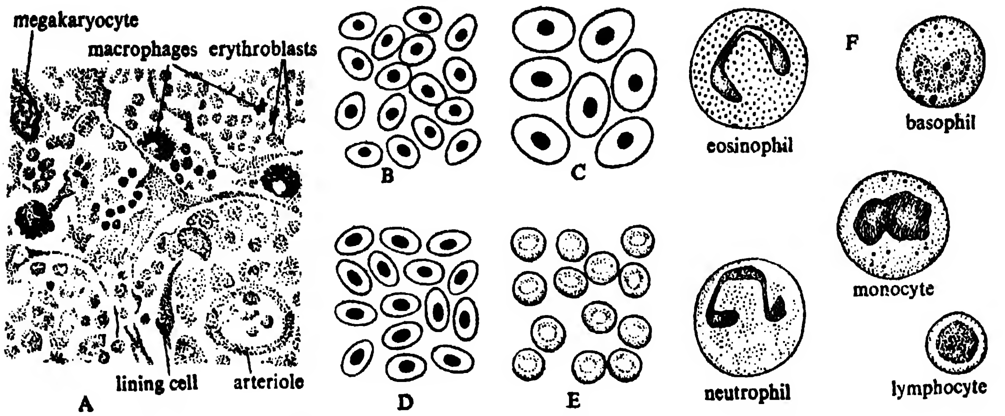


Fig. 5.5. A. Section of Rabit's bone marrow. B. RBC of fish. C. RBC of amphibia. D. RBC of bird. E. RBC of mammal. F. Leucocytes.

(*ii*) **Leucocytes.** The leucocytes occur in much lesser number than the erythrocytes. These cells, which are also known as white blood corpuscles or WBC, may be of different types (*Monocytes:* giant mononuclear amoeboid forms; *Lymphocytes:* roughly circular with one large nucleus; *Granulocytes:* amoeboid with granular cytoplasm. They are subdivided into: *neutrophils*, *eosinophils* and *basophils* depending on an

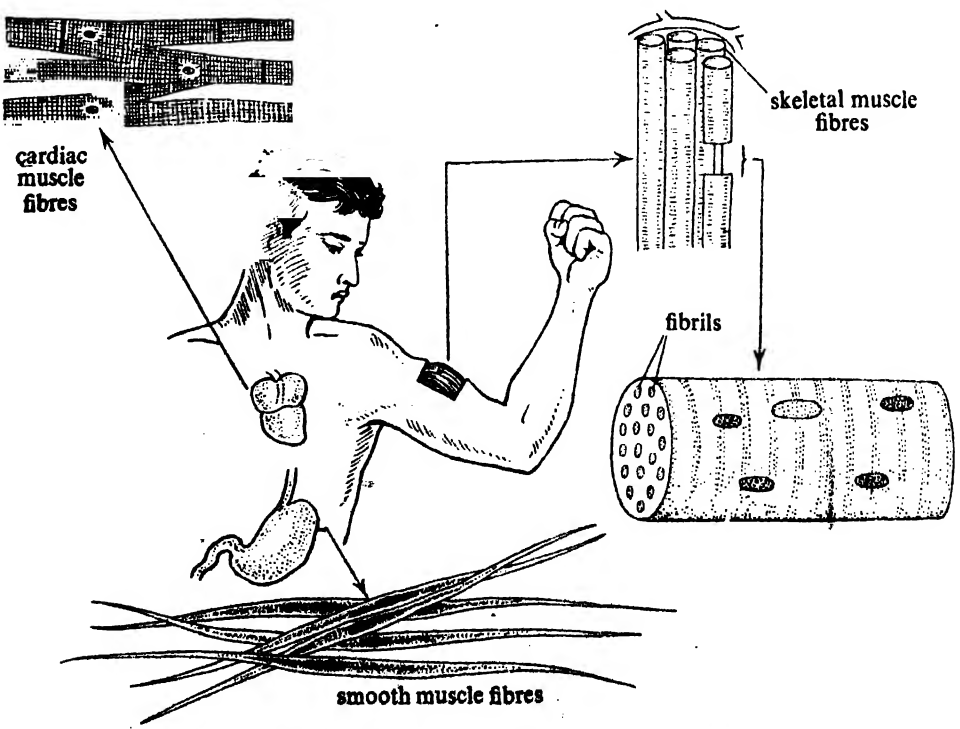


Fig. 5.6. Different types of muscular tissues. The cardiac muscles constitute the heart, smooth muscles are present in the lining of the stomach. The skeletal or striated muscles as seen in forearm are made up of fibres. Each fibre includes numerous fibrils.

affinity for neutral, acid or basic dyes respectively), which not only differ in their structures but also in their functions. Their functions include removal of dead tissue, killing of foreign bodies and carrrying of fat globules.

(*iii*) **Thrombocytes.** These are small, spindle-shaped and nucleated cells. At the time of blood shed, the thrombocytes (*thrombus*, clot; *cyte*, cell) break down under the influence of tissue fluid and produce an enzyme which helps the conversion of *fibrinogen* into insoluble *fibrin*. Fibrin forms an entangling mesh-like barrier through which the blood cells cannot easily pass and thus causes the blood to clot. The coagulation of blood prevents excess loss of blood from the injured region.

(*b*) Lymph. It is regarded as a modified tissue fluid. Generally, it is pale yellow in colour but after meal it becomes milky due to the presence of emulsified fat droplets. Lymph contains 94% water and nearly 6% solid particles which include proteins, fats, carbohydrates and other substances. Lymph also carries some wandering leucocytes. Lymph is responsible for (1) acting as a medium between blood and the cells, (2) conveying emulsified fat droplets and (3) protecting cells of the body from foreign invasion by its leucocytes.

(*c*) Bone marrow. The spaces within the bones are filled up with a special type of vascular tissue called bone marrow. The bone marrow may be of two types—(1) *Yellow bone marrow* and (2) *Red bone marrow*. The yellow marrow contains fatty tissues and does not produce blood cells. In the young individuals most of the bones contain red marrow, but with the advancement of age, in most bones (excepting upper ends of femur and humerus) yellow marrows replace the red ones. The bone marrow serves following important functions—(1) Produces erythrocytes, leucocytes and thrombocytes, and (2) through special kind of reticulo-endothelial cells it destroys the old red blood cells.

Characteristics of connective tissue:

In strict sense the term connective tissue is a loose one because it includes completely diverse types of tissues. The most important features about connective tissues are—(1) they have their own blood supply, (2) they have the ability to be converted from one type to another, e.g. conversion of cartilage to bone. Considerable amount of research work is in progress on the connective tissues. Whether cells of a particular connective tissue present in different organs have common affinity or not. Are cartilages of the knee and ear, alike? Do fibroblasts present in heart and skeletal muscles behave in same fashion? These are a few of many unanswered questions.

III. **MUSCULAR TISSUE.** A muscle means a pack of muscular tissue which is enclosed in a connective tissue called *fasciculi*, which in turn is covered by a sheath called *perimysium*. The muscular tissue is made up of *muscle fibres* which develop from a special type of cells called *myoblasts*. According to its structure the

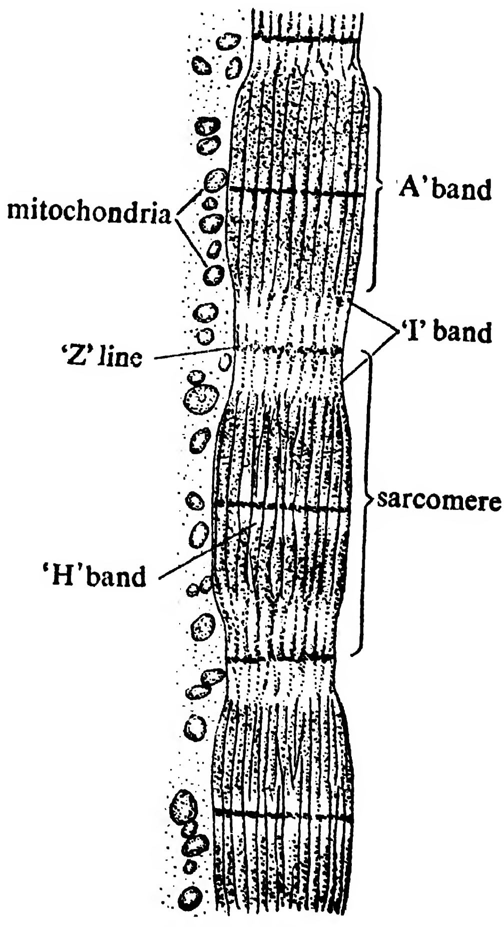


Fig. 5.7. Drawing of a single striated muscle fibril (shown in Fig. 5.6) as seen under electron microscope. The transverse deep stripe along the middle of H band is 'M' line.

fibres may be *striated, smooth* and *cardiac* (Fig. 5.6). The electron microscopy has revealed that each striated muscle fibril contains an alternate dark *anisotropic* or *A band* and a light *isotropic* or *I band.* Each I band exhibits central *Z line* and similarly A band exhibits a central hyaline transverse band called H band with a middle deep stripe called *M line.* The region between two Z lines is known as *sarcomere* (Fig. 5.7).

A. STRIATED MUSCLE FIBRES. These elongated and cylindrical muscles are also known as somatic or voluntary muscles. Each fibre is enclosed within a sheath called *sarcolemma.* Each fibre contains a mass of protoplasm called *sarcoplasm,* which includes numerous delicate parallelly arranged fibrils called *myofibrils.* In longitudinal section all myofibrils exhibit alternate dark and light segments in uniform position. This gives the striated appearance. These fibres are present in all voluntary parts and are innervated by the branch of central nervous system.

B. SMOOTH MUSCLE FIBRES. These are spindle-shaped, elongated, uninucleated cells without investing sarcolemma. Only longitudinal fibrils are present. It forms the walls of involuntary organs and are innervated by nerves from autonomic nervous system.

C. CARDIAC MUSCLE FIBRES. These are modified striated muscles in which fibres are short and branched. The branches unite to form a network or syncitium. Each fibre contains only one nucleus. This type of fibre is seen only in the wall of heart.

IV. **NERVOUS TISSUE.** This is a special kind of tissue which is responsible for receiving, transmitting and discharging various sorts of stimuli. It is made up of (A) *nerve cells* and (B) *nerve fibres* (Fig. 5.8).

A. NERVE CELLS. These are also known as *neurones.* Each nerve cell is a large spider-shaped cell having distinct nucleus and scattered *Nissl's granules* in the cytoplasm. Each cell gives rise to several short, branched fibres called *dendrites,* and a large process called *axon.* The axon may be branched along its length and each branch terminates into several finer branches called *end brush.* The axon either enters within a muscle fibre or unites with dendrites from other neurone. This union is called synapse. It was formerly thought that synapse involves a complete fusion between a fibre of axon and dendrite. But recent electron microscopic studies have shown that a gap exists between the two ends. When message travels from axon of one cell to the dendrite of another a pack of chemical substance is released from the former to the latter. It is to be remembered that a nerve cell receives message through dendrites but always sends information through the axon.

Nerve cells are divided into three types depending on the existence of number of fibres. They are:

(*i*) *Unipolar,* (*ii*) *Bipolar,* and (*iii*) *Multipolar nerve cells.* A bipolar nerve cell has one centripetal dendrite and one centrifugal axon or neurite. These types of nerve cells are abundantly found in fishes. A unipolar nerve is formed when the proximal ends of an axon and a dendrite emerge out from the cell body. A multipolar nerve cell has a single axon and several dendrites.

B. NERVE FIBRES. A nerve fibre consists of a centrally placed axon which is bounded by a sheath called *neurilemma.* The neurilemma also includes special type of cells called *Schwann cells.* Some nerve fibres contain a fatty layer called *myelin* or *medullary sheath,* between neurilemma and axon. These fibres are called *medullated fibres.* Along its path the medullary sheath is constricted at different regions, these points are called *nodes of Ranvier.* Some fibres are without myelin sheath and are called *non-medullated fibres,* which are present in autonomic nervous system. The medullated fibres arise from various parts of central nervous system.

Nervous tissue constitutes important organs like brain, spinal cord, etc., and are responsible for co-ordinating the different activities of the body. This is done by electro-chemical mechanism within neurones. According to their structure and function the three groups of neurones are known as—(1) Sensory neurones—carry impulses from various parts of the body to the brain and spinal cord, (2) Association

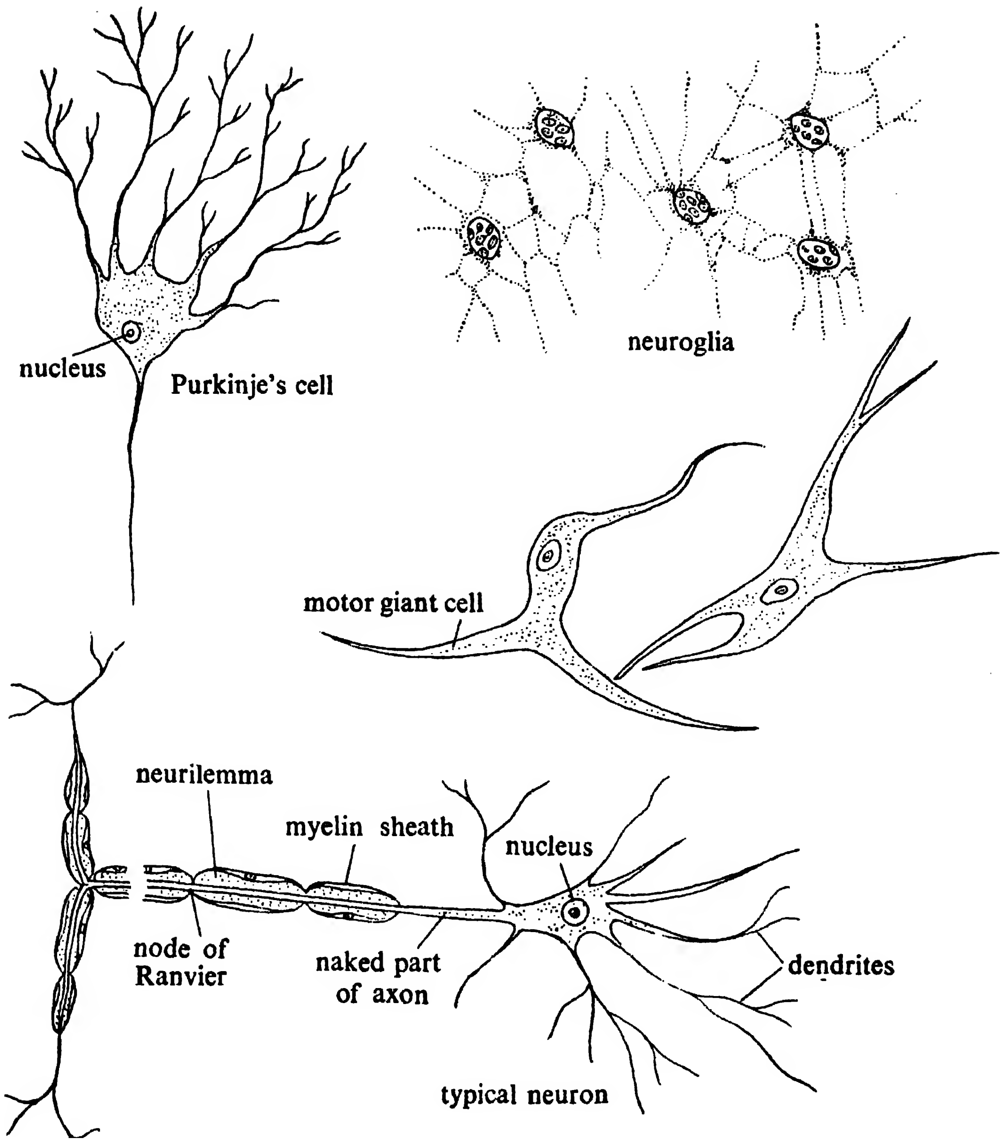


Fig. 5.8. Different types of nerve cells.

neurones—present exclusively within the brain and spinal cord to form definite circuits for nerve conduction and (3) Motor neurones—return instructions from central nervous system to the different parts of the body.

Tissue specification. The four types of tissues constitute all the different organs having different functions. Apparently these tissues appear to be same but detailed examinations have established the presence of some amount of specificity in each case. In recent years, the coming up of cell dissociation techniques and studies of mixed aggregates have thrown much light on the question of cellular affinity. When embryonic kidney and heart cells from one species were mixed up they sorted out but when any one organ (heart or kidney) from two different species (mouse and chick embryos) were put together they do not sort out. These results demonstrate that whatever may be the nature of specificity it exists at tissue grade and not at species level. All these abilities to sort out exist only at the embryonic level and

completely diminish in the adult state. Regarding the problem of tissue specificity two questions are yet to be answered (1) whether tissues from one organ can take part in the formation of other organ and (2) what changes happen in the adult state, which prevent the cells from sorting out.

SUMMARY

(i) Tissue is defined as a collection of cells having similar structure and function.

(ii) Four main types of tissues are seen in animals—epithelial, nervous, connective and muscular.

(iii) Each group may again be divided into smaller groups.

(iv) The cells taking part in the formation of tissue exhibit tissue specific affinity.

CHAPTER 6

Organs

Division of labour was initiated in multicellular forms by the formation of tissues. Hydra is a perfect example where organisation of the body remained at tissue level (Fig. 6.1). But with the progress of evolution animals with complicated organisation appeared, in which for a particular function, structural and functional associations of tissues were demanded. This gave rise to ORGANS.

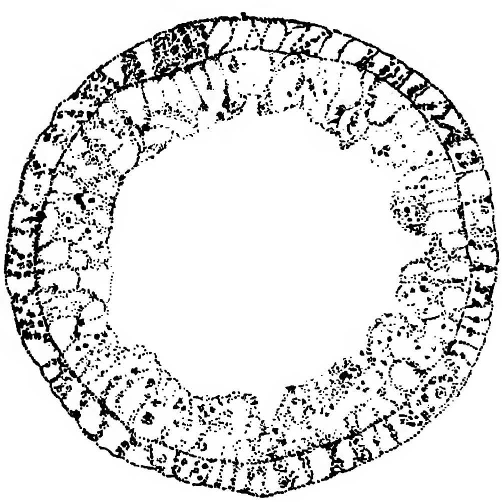


Fig. 6.1. Figure showing the transverse section of hydra, where division of labour exists at tissue level. But in higher forms—the tissues are organised to form organs, each meant for a particular function.

Generally organs are made up of several kinds of tissues. For example, (*a*) Stomach is made up of epithelial, connective and muscular tissues and its function depends upon the participation of nervous tissue (*see* Fig. 6.3A). (*b*) Eye is built up with epithelial, connective and nervous tissues (*see* Fig. 6.3B). (*c*) Skin is formed by epithelial and connective tissues. (*d*) Thyroid consists of inner glandular epithelial tissue and outer connective tissue (*see* Fig. 6.3C).

But organs may also be formed almost entirely of one kind of tissue. For example, (*a*) Brain and spinal cord are formed primarily by nervous tissue which are ectodermal in origin. (*b*) Bones and cartilages are formed entirely by connective tissues.

In recent years, considerable information is available regarding the formation and maintenance of organs. It has been found that formation of organs depends

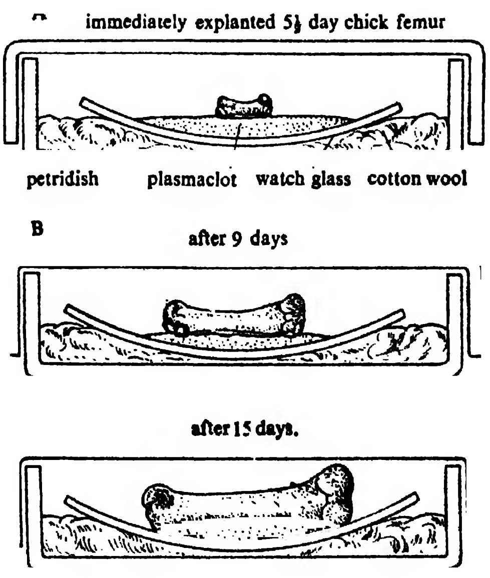


Fig. 6.2. Figure showing the development of a long bone *in vitro*.

upon the affinity of participating cells. Even cells of same organ from different animals, i.e. chick and mouse may participate to form the architecture of a particular organ. The development of "organ culture" techniques made it possible to grow many organs *in vitro* (Fig. 6.2) and thus has helped a lot to understand many facets of organ formation.

It is now an old concept that organs of a living body cannot be replaced by a spare part. The better understanding of the functions of organs has led to the successful grafting or implantation of important organs, like cornea, kidney and even heart.

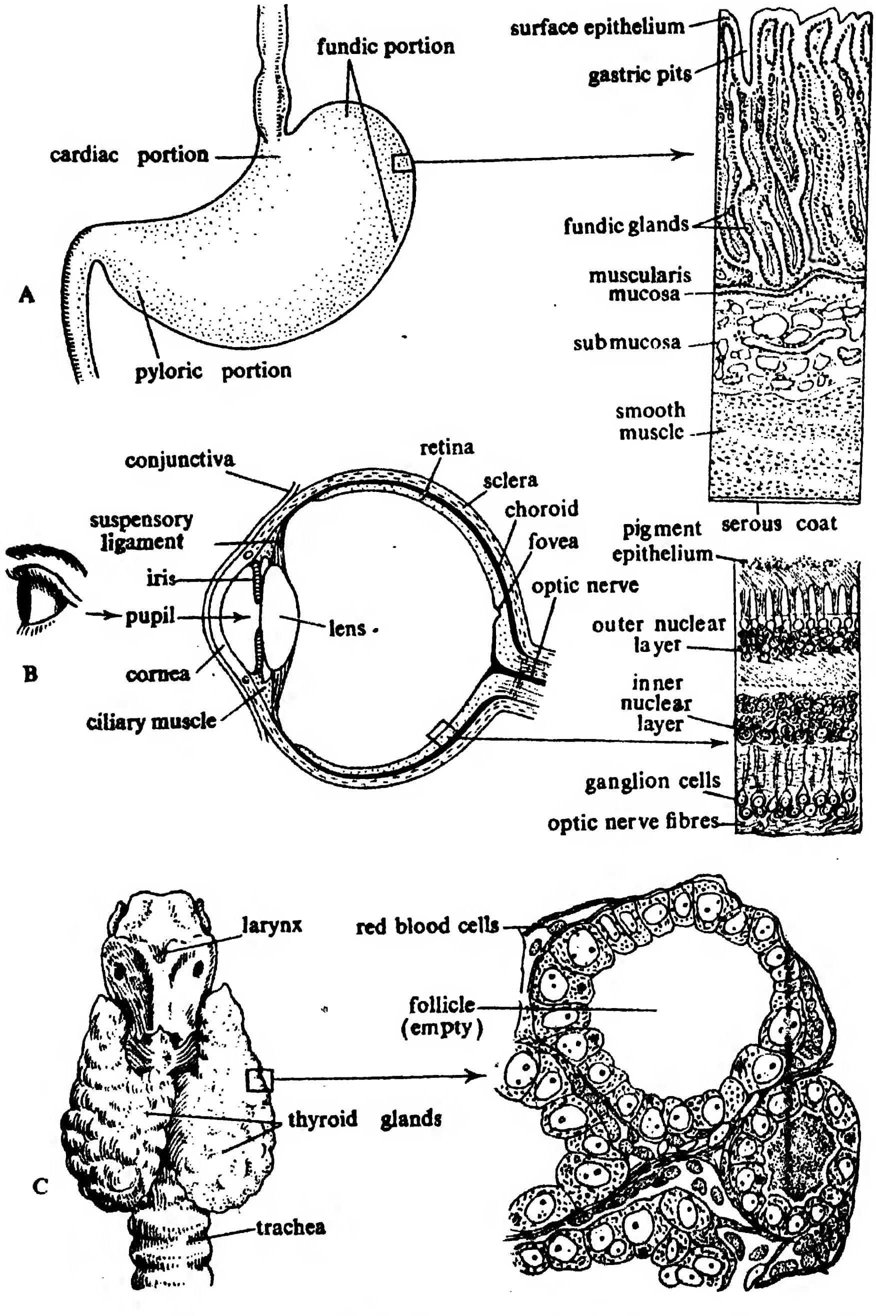


Fig. 6.3. Three organs (A) stomach, (B) eye and (C) thyroid and their histological make-up.

HISTOLOGICAL PECULIARITIES OF A FEW ORGANS ARE DISCUSSED BELOW:

TONGUE. Epithelium is of stratified squamous type and often forms *lingual papillae*. Papillae are of three types: (*a*) *Filiform*—most numerous, without taste bud, (*b*) *Fungiform*—resembles a mushroom, with taste bud, (*c*) *Circumvallete*—largest papilla, lodged within a trench. Loose areolar connective tissue forms the core of the papillae. Taste buds contain two types of cells—*gustatory* and *subtentacular*. Bundles of stratified muscle fibres interlace in all directions.

SPLEEN. Spleen is a lymphatic organ. It plays many functions—(*i*) destroys old RBC, (*ii*) stores excess of RBC, (*iii*) manufactures RBC, (*iv*) produces antibodies and (*v*) destroys harmful microbes. A sectional view shows the presence of a connective tissue *capsule* which extends inside the gland as the *trabeculae*. It is divided into *cortex* and *medulla*. The medulla contains *white pulp* (rounded aggregations of *splenic corpuscles*) and *red pulp* (rest of the portion with red texture due to the presence of RBC).

PANCREAS. Mixed type of gland consisting of two altogether different glandular entities: (*a*) *Multiple alveolar type* (*Exocrine*): Each alveolus is walled by truncated pyramidal cells. Nuclei in these cells are situated towards the basal membrane. The alveolar cells have zymogen granules and deeply stained basophilic bodies towards the basement membrane. Presence of some flattened cells in the lumen of alveolus (centro-acinar cells) is the characteristic of pancreatic alveolus. (*b*) *Islets of Langerhans* (*Endocrine*): Islets include three types of cells, α (alpha), β (beta) and γ (gamma) cells. The gamma cells are regarded to be the precursors of α (alpha) and β (beta) cells. In human islets a fourth type of cell—the δ (delta) cells have been described. The β cells produce the hormone—*Insulin*. This fact is experimentally attested by causing Alloxan diabetes (treatment of Alloxan, a derivative of Urea, which causes degeneration of β cells). The islets are special areas in between the pancreatic acini and consist of irregular clumps of cells, capillaries and reticular tissue. Islets are not encapsulated but remain separated by reticular fibres.

LUNG. It is formed by round, transparent and irregular air cells or alveoli. Each alveolus is lined by large irregular and flattened squamous epithelial cells. Desquamated dust cells may be seen. Bronchioles and lymphoid tissue may be present.

KIDNEY. It is formed of an outer *cortex* and an inner *medulla*. Cortex is externally covered by a fibromuscular capsule.

(*a*) *Cortex:* It shows (*i*) Tuft of blood vessel forming thousands of *Renal corpuscles* or *Malpighian corpuscles* encircling network of blood vessels—the *glomerulus* and (*ii*) *excretory canals*.

(*b*) *Medulla:* The medulla includes *uriniferous tubules* and *connective tissues*. The structure of epithelial cells varies in the different length of the tubules flattened (at the capsule), granulated cubical (convoluted tubule) and non-granulated cubical (collecting tubule).

ADRENAL. Adrenal or suprarenal is an endocrine gland situated above each kidney. A sectional view reveals the presence of an outer *cortex* and an inner *medulla*. The cortex is encapasulated by a connective tissue capsule. The cortex is subdivided into three zones, viz. (*i*) *Zona glomerulosa*, (*ii*) *Zona fasciculata* and (*iii*) *Zona reticularis*. The cortex produces a hormone called the *cortin*. The medulla is composed of *chromaffin cells* which secrete a hormone named the *adrenalin*.

TESTIS. *Tunica albugenia and vasculosa* form the outer capsule of the testis. Germinal epithelium surrounds the seminiferous tubules. Each tubule contains a basement membrane on which are arranged from periphery to the lumen: (1) *Spermatogonia*—cubical cells with oval and compact nuclei, (2) *Spermatocytes*—large cells with dividing nucleus, (3) *Spermatids*—small, simple cells with round nuclei, and (4) *Spermatozoa*—elongated cells in the lumen. Associated with the germinal epithelium are the *Sertoli cells* which are tall

and irregular in outline. These cells extend from the basement membrane to the lumen. *Interstitial or Leydig cells* occur in the angular spaces between seminiferous tubules.

OVARY. The outer germinal epithelium is columnar or cuboidal. Inner stroma or fibrous layer is divisible into a peripheral part and central part. Immature Graafian follicles are present in the peripheral stroma as large spherical cells with prominent round nuclei. Mature follicles remain embedded within the central part of the stroma. The *corpus luteum* as a mass of yellowish stained tissue and vascular fibrous tissue is present.

The structure of a mature Graafian follicle: (*a*) *Theca folliculi*, (*b*) *Membrana propria*, (*c*) *Membrana granulosa*, (*d*) *Discus proligerous*, (*e*) *Zona pellucida*, (*f*) *Vitelline membrane* containing *vitellus* and (*g*) *Germinal vesicle* containing the *germinal spot*.

ARTERY. Presence of three distinct coats. The outer coat (*tunica adventitia*) is composed of connective tissue having numerous elastic fibres. The middle coat (*tunica media*) is thick and made up of network of elastic *fibres* and circularly arranged plain muscle fibres. The innermost coat (*tunica intima*) contains highly refractile and elastic *membrane* of *Henle*, *subendothelial layer* and *endothelial layer*.

VEIN. The three coats are not so marked as in artery. The outer coat is well developed. Instead of muscular and elastic tissues, there are white fibrous tissues in the middle coat. In the inner coat the endothelial cells are elongated and refractile membrane of Henle is usually absent.

THYROID. From the outer fibrous tissue layer arise the *trabeculae*. There is presence of numerous alveoli which are either spherical or oval. Each alveolus has a lining of cubical epithelium and contains colloidal material in its lumen. Some alveoli may be empty (Fig. 6.3C).

LIVER. Units of liver are *liver lobules*. Each lobule is surrounded by connective tissue materials containing collagen. A particular lobule is composed of polyhedral cells (often binucleate) radiating from a central canal—the hepatic vein.

Associated with one liver lobule, a portal canal occurs which is composed of a trinity of: (*a*) *Portal artery*, (*b*) *Portal vein*, and (*c*) *Bile duct*. All these are surrounded by connective tissue materials forming *Glisson's capsule*.

GASTRO-INTESTINAL TRACT. The wall is composed of four principal layers: (*i*) *Tunica adventitia or serosa*, (*ii*) *Tunica muscularis*, (*iii*) *Tunica submucosae* and (*iv*) *Tunica mucosae*. The serosa is made up of loose connective tissue. The tunica muscularis has smooth muscles oriented in circular and longitudinal fashion. The tunica submucosae consists of collagenous fibres with blood vessels and plexuses (*Meissner's plexus*) of autonomic nerve fibres. The tunica mucosae has three components: surface epithelium, lamina proparia and muscularis mucosae.

STOMACH. In addition to these typical features, the mucous membrane is relatively thick with numerous small simple tubular cardiac glands (Fig. 6.3A). There is no gland in submucosa except the pyloric part. The muscularis layer has, in addition to circular and longitudinal muscles, obliquely disposed muscles. The mucous membrane comprises of surface epithelium, parietal or oxyntic cells, mucous neck cells and zymogenic cells.

SMALL INTESTINE. Like all other portions of the gastro-intestinal tract, the small intestine also contains usual four coats from outside inward, namely, *serous coat*, *muscle layer*, *sabmucosa* and *mucosa*. The peculiarities are chiefly confined to the mucous or the innermost layer. They are: the mucous membrane, lined by columnar epithelium, is thrown into finger-like projections called *villi;* Lymphoid nodules, called *'Peyer's patches'* occur in the mucous membrane; presence of few goblet cells in the epithelium of the villi.

The peculiarities of the different regions of the gastro-intestinal tract is given in Table 3.

TABLE 3

Comparative histological picture of the different regions of the alimentary canal

Points	Oesophagus	Stomach	Small intestine	Large intestine
Surface epithelium	Striated-squamous. Becomes keratinised in some mammals. Thrown into longitudinal folds.	Simple-columnar.	Simple-columnar.	Simple-columnar. Becomes stratified squamous towards recto-anal junction.
Lamina propria	Collagen fibres are abundant. Papillae are present. Glands are few.	Loose connective tissues with closely-packed glands.	Projects into villi which contain characteristic capillary bed. Some smooth muscle fibres and glands. Lymph nodules aggregated as Peyer's patches in ileum.	Thicker-numerous tubular glands and large lymph nodules.
Muscularis mucosa	Thick - muscle fibres are oriented longitudinally.	Two layers—thin, outer is composed of longitudinal and inner with circular muscles.	Two layers—thin.	Not well-marked, may be absent at places.
Villi	Absent, but longitudinal folds are present.	Absent.	Present.	Absent.
Lymphatic tissue	Sparse.	Rich.	Rich.	Rich.
Submucosa	Contains mucous glands.	Form rugae (large folds).	Raised into folds called *plicae circulares*. Glands of Brunner are present in duodenum.	No. plicae. Lymph nodules project into the submucosa.

TABLE 3 (contd.)

POINTS	OESOPHAGUS	STOMACH	SMALL INTESTINE	LARGE INTESTINE
Muscle layer	Two layers—thick, outer longitudinal and inner circular. Skeletal in upper and smooth in lower region.	Three layers — outer longitudinal, middle circular and inner oblique. Smooth muscles.	Two usual layers of smooth muscles.	Two usual layers of smooth muscles. Taeniae (three bands of fibres) are present in longitudinal layer. No taeniae in rectum.
Glands	Mucous glands in submucosa.	Large—three types in lamina propria: (*i*) Cardiac, (*ii*) Fundic and (*iii*) Pyloric glands.	Glands of Brunner in duodenum only. Crypts are present.	Globlet cells are increasing towards lower end.
Digestive functions	Absent.	Liquefaction of food-protein digestion begins.	Main digestion of proteins, fats and carbohydrates. Absorption of food.	Absorption of water and concentration of residue.

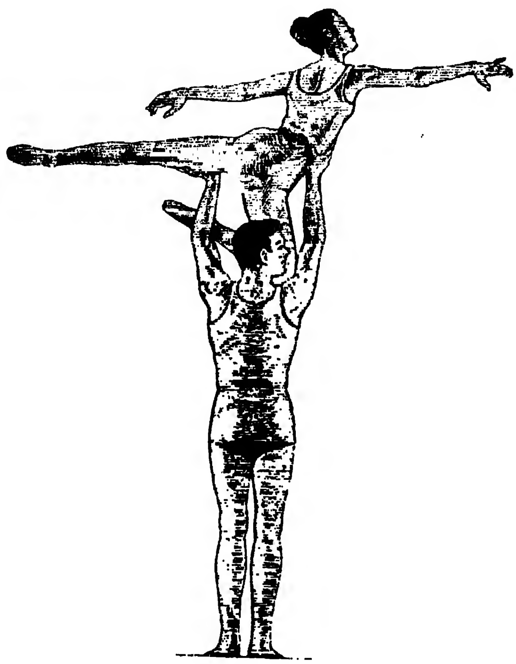
SUMMARY

The organ is collection of one or more tissues. In higher forms the organs are built up in more complicated way. The wear and tear of organ is generally repaired automatically. In recent years, it has been possible to grow organs *in vitro* and at the same time it is feasible to transfer them.

CHAPTER 7

System

Under experimental conditions the organs can live and grow outside the body, but their proper functioning depends upon the participation of several organs to do a specific vital activity. This participation of several organs constitutes a particular system. The co-ordination between organs of different systems can only build up the 'internal milieu', which is essential for the existence of a particular organism. Figure 7.1 illustrates an example of physical activity, which involves co-ordination of different systems like skeletal, muscular and nervous.



7.1. An example of perfect co-ordination

In the multicellular forms above the coelenterates, several organs take part to form a system for particular function. In a higher organism following systems (Fig. 7.2) are seen.

I. **INTEGUMENTARY SYSTEM.** The organ involved in this system is skin and its various derivatives, i.e. hairs, scales, feathers, nails, horns and hooves. The primary function of skin is *protection*, but it performs several other functions.

II. **MUSCULAR SYSTEM.** This is probably the largest system in an animal body which includes *muscles*. It is concerned with movement, which includes locomotion of the individual and also the movement of different organs, e.g. heart, alimentary canal. The muscles are made up of muscular tissues and connective tissues.

III. **SKELETAL SYSTEM.** It is composed of skeleton. When skeleton is present outside the body it is called *exoskeleton*, e.g. coverings of prawn, insects, molluscs or scales, nails and claws in vertebrates. Among the invertebrates the exoskeleton is built up of chitin, calcium, etc. This is periodically replaced by a process called moulting. Among the vertebrates the skeleton is internal and called *endoskeleton*. It includes bones, cartilages and ligaments. In contrary to exoskeleton this is living, i.e. provided with blood supply and nerves. This system constitutes the framework and support of

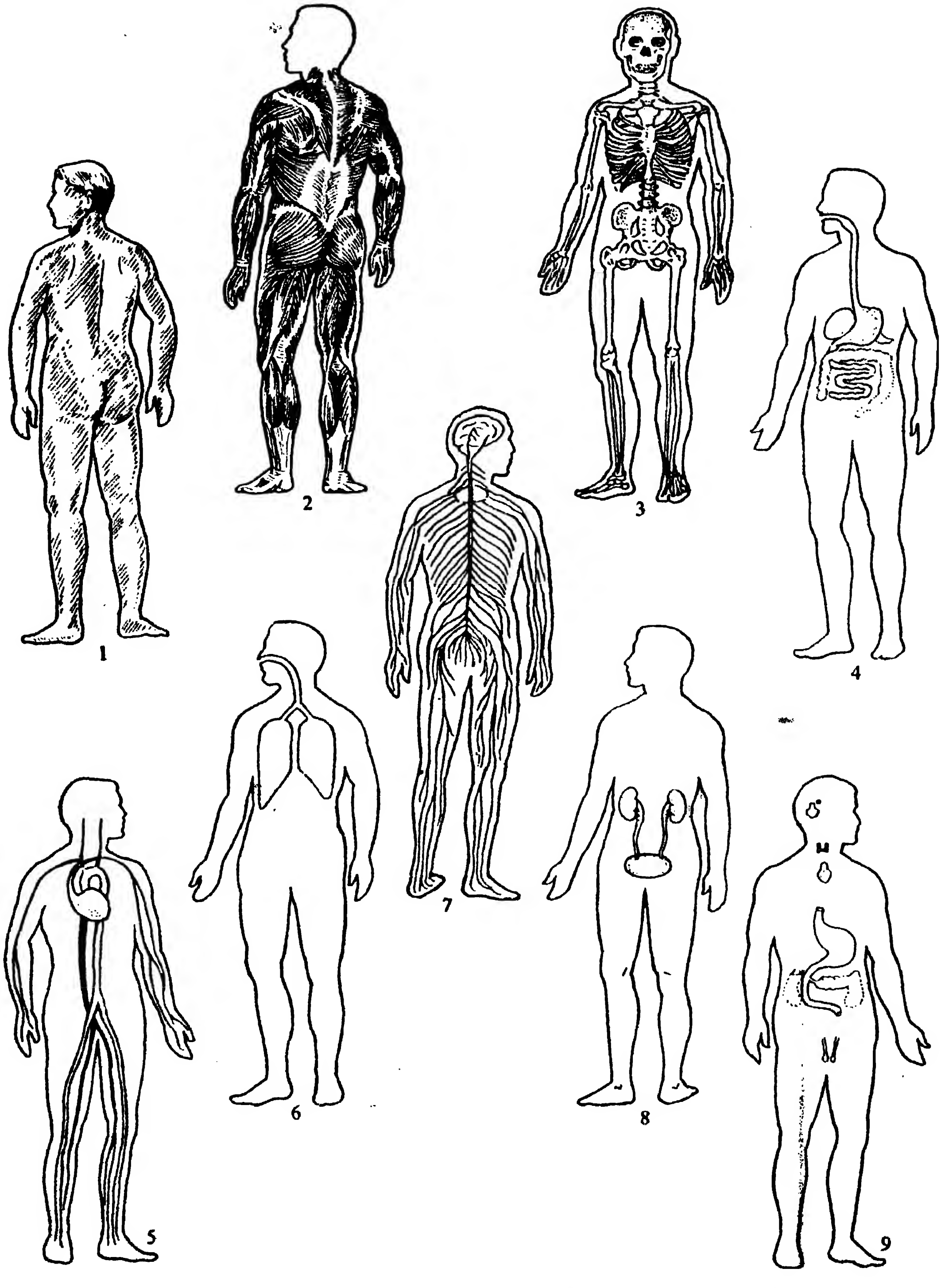


Fig. 7.2. Nine essential services in human body. (1) Integumentary system as external lining. (2) Muscular system for movement. (3) Skeletal system for support and rigidity. (4) Alimentary system for nutrition. (5) Circulatory system for transport. (6) Respiratory system for the supply of oxygen and removal of carbon dioxide (7) Nervous system for co-ordination. (8) Excretory system for removing excess and metabolic wastes and water. (9) Endocrine system for chemical regulation.

the individual. Exoskeleton has got nothing in common with endoskeleton except its hardness.

IV. **DIGESTIVE SYSTEM.** It is responsible for nutrition. Different organs included within this system are teeth, tongue, oesophagus, stomach, intestine, liver and pancreas. They work to take in food (ingestion), to break the complex organic molecules into simpler forms (digestion) and to reject excrementitious products (egestion).

V. **RESPIRATORY SYSTEM.** This system in one hand ensures the requirement of oxygen in tissues and on the other works to evacuate the carbon dioxide from the tissues. In different animals the organs of respiration differ and following organs are generally found to carry the function of respiration:—gills, trachea, lungs, skin and lining of the buccal cavity.

VI. **EXCRETORY SYSTEM.** Metabolic activities produce waste products. These substances (which are chiefly nitrogenous) together with excess of water are removed from the body by excretory system. Within invertebrates the excretory organs are nephridia, green glands, coxal glands, Malphigian tubules. The excretory organs in vertebrates are known as kidneys.

VII. **CIRCULATORY SYSTEM.** For co-ordination, the important requisite is contact between different systems. This is done by circulatory system which includes (A) two sets of circulatory fluids—blood and lymph, (B) vessels for the flow of these fluids, and (C) pumping organ called the heart. In invertebrates the circulating fluid comes out of the vessels to bathe the tissue space but within vertebrate body blood flows through a closed system of vessels. The circulation in the former group is of open type and in the latter group it is called the closed type of circulation. This system not only works as porters of the living body but are engaged in defence against foreign invasions.

VIII. **REPRODUCTIVE SYSTEM.** Reproduction or multiplication by self-duplication is an important feature of living body. In the multicellular animals organs carrying out this function are known as ovary (in females) and testis (in males). These organs form specialised cells which pass out through definite tracts. All animals possess specialised structures to assist in bringing these two types of cells closer. Certain glands are often seen to be associated with this system to help in the process of reproduction.

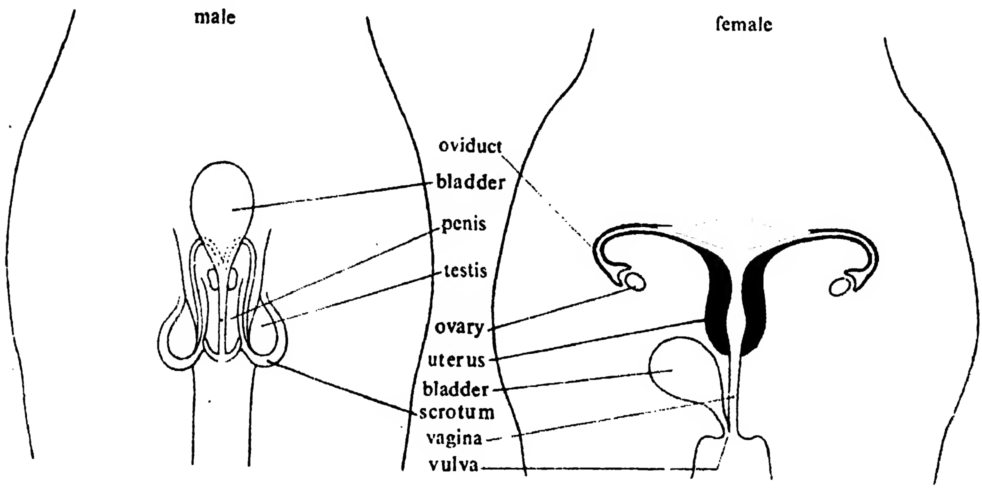


Fig. 7.3. Reproductive system of a Man and a Woman.

IX. **NERVOUS SYSTEM.** It is made up of a special kind of tissue, namely the nervous tissue. It has the same developmental origin as epidermis. Important organs, like brain and spinal cord perform the functions of response to stimuli and co-ordination of different parts of the body. These organs are assisted by different

peripheral and sympathetic nerves and many organs like eye, ear, tongue, nose and skin work as ports of entry for different stimuli.

X. **ENDOCRINE SYSTEM.** It includes certain glands, e.g. Thyroid, Parathyroid, Pituitary, Adrenal, Thymus, Islets of Langerhans, etc., which pour their secretion directly within blood. The secretion is known as *hormone*, which acts in a magic way and takes part in the chemical control of the body. A particular hormone is of same chemical nature in different groups of animals. Only a specific quantity of hormone is required for the proper maintenance of the body. Any deviation in quantity upsets the chemical control of the body and creates abnormality through metabolic disbalance.

SUMMARY

Several organs take part to form a system which is responsible for mainly one function. These different systems are co-ordinated by the nervous system and the work of all the systems together are expressed as the activity of an individual.

PART THREE

DIVERSE MANIFESTATIONS OF LIFE THROUGH ANIMALS

A visit to the zoo instantly reflects the diversity in the animal world. We love to see the graceful elephant, elegant giraffe and striped zebra. We do appreciate a roaring lion, a dancing peacock, a jeering monkey and a moving turtle. There are many more to mention, but still the zoo is a limited man made home for diverse animals collected from different parts of the world.

A glimpse of Nature's yard will flash the marvel and the extent of diversity. Animals, from the size of microscopic specks to giant forms, inhabit the earth and occupy all possible environments.

More than a million types of animals are known to man. It is not possible to study all of them within the limit of a book. For this reason, this part is devoted to discuss some *examples of animals* to understand the extent of diverse manifestations of life.

CHAPTER 8

Inventory of Animals

In a library or a departmental store, you must have noticed that all the articles are orderly arranged. This order helps in finding out the right thing in right place. It expedites the work and avoids confusion. Such orderly arrangement is classification and its purpose is to create an order in disorder. The classification is essential to handle various items of diverse kinds. And same is true about living organisms.

We find that there are innumerable animals and no two individuals (excepting the identical twins) are exactly alike. It is not possible in one's lifetime to examine all of them. For this reason it is felt to group the animals (Fig. 8.1).

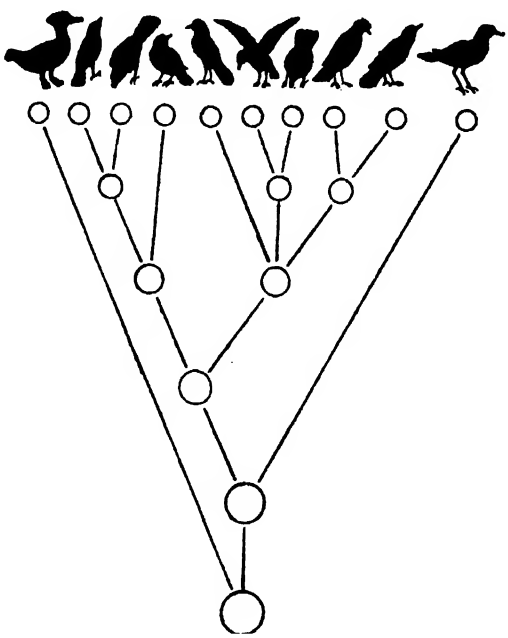


Fig. 8.1. Classification of ten different birds. Note that the classification in one hand indicates interrelationship and at the same time their origin.

The branch of Biology which deals with the grouping of animals is termed as *taxonomy* or *classification* or *systematics*. Taxonomists or the persons specialised in making the inventory, started it as a routine clerical work, but recent approach to the science of Biology has added a new dimension to the science of classification and the new systematics has emerged out as a synthesis of progress in all the major disciplines of Biology.

TAXONOMIC CRITERIA

In a library, books are arranged according to the subjects or according to the authors. Here the books are the *units*, which are first of all recognised and defined before grouping. In the organic world a living organism is the unit and the essential prerequisite in taxonomy is correct recognition and definition of these units. This can only be done through careful study of individuals. The process of taxonomy thus involves two distinct steps (1) correct definition and recognition of the *unit* and their relationships and (2) application of suitable designations to the units and to different groups which include them. The former is called *classification* which includes study of characters and grouping of individuals, while the latter is termed as ***nomenclature*** or ***naming***.

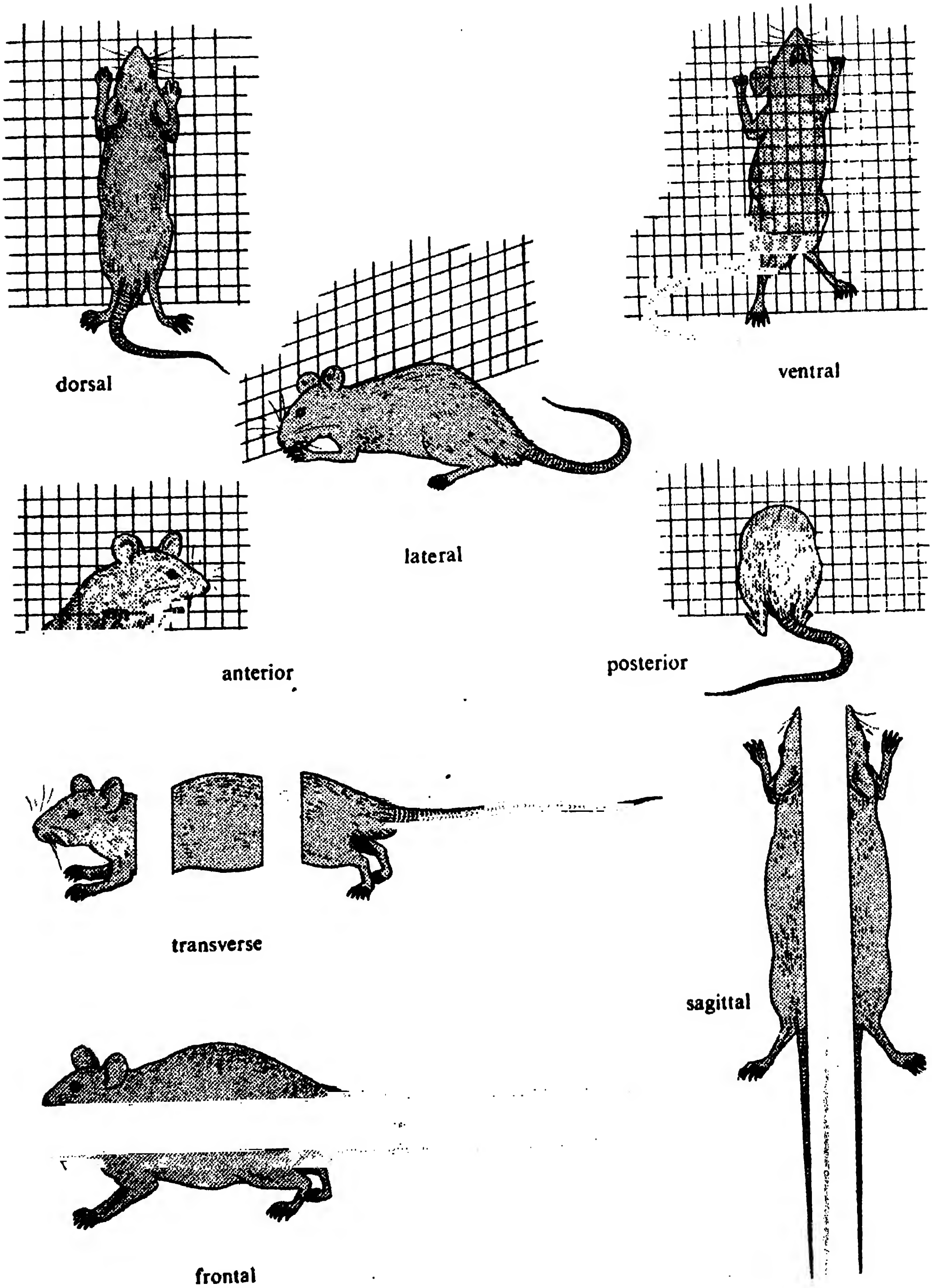


Fig. 8.2. For the convenience of study, the animal body is divided into a number of regions-dorsal (usually the part which is away from the ground), ventral (usually the part towards the ground), lateral (two sides of the body), anterior (the end which usually moves forward during movement and bears mouth) and posterior (the end opposite to anterior). The entire body may also be divided into three planes, transverse, frontal and sagittal.

SEARCH OF CHARACTERS AND THE GUIDING PRINCIPLES

Each and every individual has certain characters of its own. These characters are expressed through shape, size, symmetry, segmentation, appendages, skeleton, sex, embryonic development and larval form. Figures 8.2 and 8.3 explain the basic plan which is followed in studying the characters of animals.

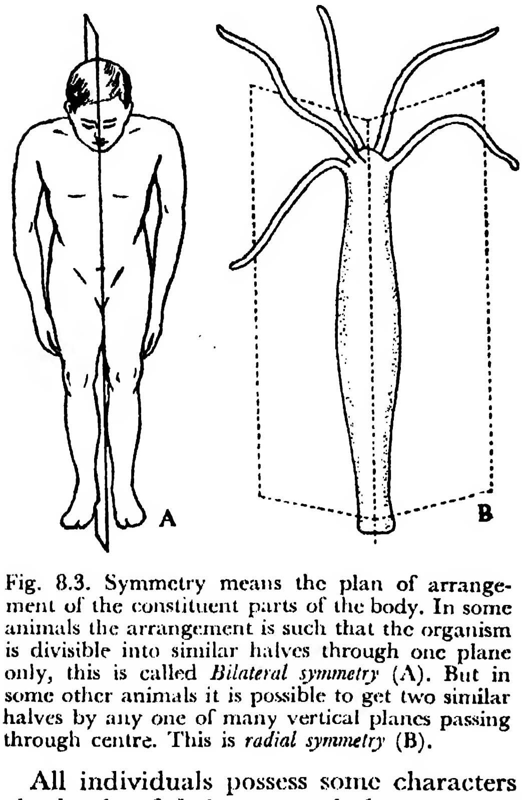


Fig. 8.3. Symmetry means the plan of arrangement of the constituent parts of the body. In some animals the arrangement is such that the organism is divisible into similar halves through one plane only, this is called *Bilateral symmetry* (A). But in some other animals it is possible to get two similar halves by any one of many vertical planes passing through centre. This is *radial symmetry* (B).

All individuals possess some characters absolutely of their own and there are instances when individuals often resemble some more closely than others. The structures which have similar developmental origin are called *homologous* structures. And the structures which have different developmental origin but show functional similarities are called *analogous* structures. The forelimb of man and pectoral fin of fish are homologous structures though they have no apparent similarity. But wings of birds and wings of insects are analogous structures because in spite of functional similarity they have separate developmental origin. It is to be remembered that homologous structures may have functional dissimilarities but analogous structures never possess common developmental origin. Basing on the presence of homologous and analogous characters the Zoologists attempted to group the animals and in doing that they are guided by two principles:

(1) Animals possessing many homologous structures owe their similarities to a common ancestor.

(2) Such variant groups which agree with one another in some features are related to one another.

HISTORICAL ASPECT OF ANIMAL CLASSIFICATION

The attempt to classify animals dates back to 384–322 B.C. At that time Aristotle put forward a scheme of classification of animals on the basis of some common characteristics. He divided the animal kingdom into two major divisions:

I. **ANAIMA.** This group included all the invertebrates and is characterised by the *lack of red blood.* As examples of this group the sponges, coelenterates, arthropods, molluscs were put forward.

II. **ENAIMA.** This group included the vertebrates, *having red blood.* The Enaima was again subdivided into two categories:

A. *Oviparous.* It included the egg-laying vertebrates, e.g. the fishes, amphibians, reptiles and birds.

B. *Viviparous.* This group on the other hand included the vertebrates where the youngs are born alive, e.g. the mammals.

John Ray (1627–1705) was the first naturalist to give the modern concept of species and tried to classify the animals. Linnaeus (1707–1778) introduced a complete biological system of naming and classification of animals. Linnaeus divided the animal kingdom into several classes: Mammalia, Aves, Amphibia, Pisces, Insecta and Vermis. The class Vermis includes all invertebrates except the insects and is divided into the following orders: *Intestina, Mollusca, Testacea, Lithophyta* and *Zoophyta.* Other scientists like Cuvier (1769–1832), Lamarck (1744–1829), Leuckart (1823–1898), Haeckel (1834–1919), Ray Lankestar (1847–1929) threw much light to find out a general principle in biological classification and contributed much to the science of taxonomy. Both Cuvier and Lamarck distinctly separated the invertebrates and vertebrates. Lamarck divided the invertebrates into: *Mollusca,*

Cirripedia, *Annelida*, *Crustacea*, *Insecta*, *Arachnida*, *Vermes*, *Radiata*, *Polypes* and *Infusoria*. But Cuvier classified the invertebrates into: *Mollusca* (including brachiopods and barnacles), *Articulata* (including annelids and arthropods) and *Radiata* or *Zoophyta* (including rest of the invertebrates). Leuckart's contribution on systematic zoology is noteworthy. He recognised the phyla, *Protozoa*, *Coelenterata* (sponges are included), *Echinodermata*, *Vermes*, *Arthropoda*, *Mollusca* (Tunicates are included) and *Vertebrata*. The defects of the above systems were rectified by Carl Vogt (1851). He classified the Vermes into *Annelida*, *Rotatoria*, *Platyelmia* and *Nematelmia*. Gagenbaur (1859) changed the names of the last two groups to *Platyhelminthes* and *Nemathelminthes* respectively. Of the various taxonomical names, *Protostomia* and *Deuterostomia* have been extensively used by many taxonomists. The Bilateralia is divided into: *Protostomia* (Blastopore becomes the mouth) and *Deuterostomia* (Mouth is a new formation). But such groupings are not regarded as the true taxonomic divisions.

THE SYSTEM OF CLASSIFICATION AS DONE BY LINNAEUS

In order to place the known organisms in their proper systematic status Linnaeus employed certain primary categories, viz. *Kingdom*, *Phylum*, *Class*, *Order*, *Family*, *Genus* and *Species*. In addition to those ranks, certain intermediate categories like *Subphylum*, *Subclass*, *Superorder*, *Suborder* and *Subfamily* were created to meet the specific needs. Linnaeus first placed closely resembling organisms in a species then similar species under a genus and several genera under a family and so on. The taxonomists, before Linnaeus, were engaged in classifying animals only for the sake of identification. It is Linnaeus who, for the first time, suggested a scheme to establish kinship amongst different members.

SYSTEM OF CLASSIFICATION—THE MODERN APPROACH

Linnaeus and his followers believed that species never change. The system of classification followed by them is an *artificial system*. While defining a species only the morphological characters were considered by them. But in recent years, the approach of biology has radically changed. Today, while ascribing characters, physiological, genetic, ecological and phylogenetic points are taken into consideration. These new insights have moulded the idea of species. Dobzhansky (1937) has defined the species as a group of individuals which while passing through the ordeal of evolution has been physiologically and genetically incompatible of inbreeding with other group of individuals. Mayr (1947) called a species as a group of inbreeding individuals which are separated from other groups from the point of view of reproduction. Simpson (1961) viewed species as "a lineage evolving separately from others and with its own evolutionary role and tendencies."

The most important finding has come from the studies of genetics. It is known that all the morphological, physiological and ecological characters are based on genes which are present over the chromosomes.

The difference between one species and another, rests on the genetic make-up. In certain cases, e.g. butterfly, it has been recorded that individuals having similar chromosomal make up (i.e. members of the same species), exhibit differences in morphological features. Such variations within the same species are now considered as *infraspecies*. It is propounded that the expression of characters of a particular species is not due to a definite set of genes in one individual but a collective *gene pool* of all the inbreeding individuals. The species today is thus regarded as "the sum of all its variations".

With the new concept of species in mind modern taxonomists want to establish a *natural system of classification*. The goal of which is (1) to establish correct interrelationship amongst the existing forms (horizontal classification) and (2) to find out the relationship of existing forms with their ancestral forms (vertical classification).

This has made the task more complicated. Two factors—*difficulty in the proper assessment of characters* and *non-availability of suitable fossil materials*, are acting as hindrances to complete the classification. For this reason in various instances (e.g. insect) morphological features and phylogenetic speculations are still used, which has resulted into the coming of a mixed system of classification. The mixture is between *natural system* and *artificial system*.

NOMENCLATURE OR NAMING OF ANIMALS

Names are given to all animals. The name of a particular animal differs in different languages. Even within the same country one animal is known in different names in different regions. To avoid this intricacy of names, it was proposed to give them a *scientific name*. Such scientific names are latinised words given as per the International Code of Zoological Nomenclature.

A particular organism is given a *generic name* and a *specific name*. The name of genus indicates what kind of animal and the name of species denotes what exact kind it is. Such paired naming is greatly emphasised in the Linnaean system and this system is called the *Binomial Nomenclature*. For example, the biological name of the domestic cat is *Felis domestica*. The generic name of the organism is a noun and starts with a capital letter while the specific name is an adjective and is written in small letters (of course, there are exceptions). The generic name is a common noun and instead of one individual it means an entire group. As they are written in Latin the generic as well as the specific names are italicised in print and are underlined while writing. Sometimes it becomes imperative to recognise subspecies or varieties within a species and is given a third specific name. Such system of naming is known as the *Trinomial Nomenclature*. The scientific name of the lion is *Panthera leo* (Linn.). The same species of the specimen collected in different countries show minor differences from the original form. So a third subspecific name becomes necessary in many cases. The scientific name of the Indian lion is designated as *Panthera leo persica* (Linn.). After the specific name the name of the author, who first identified the particular species, is given in an abbreviated form.

The *adoption of latinised names for the organisms* and *the scheme of classification according to hierarchy* are the two main themes of the classificatory secret of Linnaeus. The selection of Latin as the language of nomenclature is quite reasonable because it remains unchanged through generations and is not subjected to grammatical changes as it happens in other vernacular languages.

The need for a code to give a scientific name to every species was first realised by British Association of Advancement of Science in 1842, when a set of rules were framed by it. This was also felt by similar learned bodies of countries like USA, France and Germany and they developed codes for their respective countries.

In 1889, at the International Congress of Zoology in Paris, discussions were made to find out some common code of nomenclature. First version of the code was adopted in the 5th International Congress of Zoology in Berlin. In the session of the same congress in 1958 the codes were re-written and published in 1961. This code is concerned only up to the naming of superfamily.

The naming of an animal is governed by the International Rules of Zoological Nomenclature. There are many rules concerning the Zoological Nomenclature. Of the rules, some important ones are cited below:

(1) The generic name of a plant and an animal may be same, but this system is to be avoided as far as possible.

(2) The name of a species is to be binomial and a subspecies to be trinomial.

(3) The scientific names of animals or plants must consist of Latinised words.

(4) The generic name must be a single word and should be written with an initial capital letter. It must be used as a nominative singular.

(5) The specific name of an animal or plant must be written with an initial small letter excepting the cases where the specific name is derived from the name of a person.

(6) The specific names must be adjectives agreeing grammatically with the generic name of the organism.

(7) When there is a subspecies, the subspecific name must be put immediately after the specific name. There should not be an interposition of any mark of punctuation between the specific and subspecific names.

(8) The original spelling of a name must be retained unless there is any evident error.

(9) The person who first publishes the name of an animal or plant, is the author of a scientific name.

(10) The application of the law of priority will start with 1758, the year of publication of Linnaeus' *Systema Naturae* (10th edition).

(11) A generic or specific name, once published, cannot be changed or rejected. The generic or specific name, however, may be rejected if it has been used previously for some other animal.

UNDERLYING PRINCIPLES IN THE CODE

A. **Priority.** Any name given to a species or genus for the first time will be accepted provided:

1. The author himself is fully satisfied about his own intention.

2. The author has followed the system of Linnean binomial nomenclature.

3. The author has published his contention in a scientific book or journal which has been properly printed and widely circulated.

B. **Homonymy.** The word given as name in one context must not be used again in naming another species or genus.

C. **Type.** One specimen must be selected by the author as **Holotype** before giving the name of a species. Other individiuals belonging to this species become **Paratype.** This is applicable in naming a genus or a family. Each new genus must have a type species, each family with a type genus.

WHY CLASSIFICATION? WHY NAMING?

Animals bother neither about their position in the animal kingdom nor they care for any ornamental name. Why then classification and naming are considered to be so important? Surely it is not to bewilder the beginners of Biology with high sounding names. What is then their purpose?

As mentioned earlier, there are millions of animals. It is not possible to study each and every one of them. Thus a scientist examining the pancreatic enzymes in dog cannot go on killing each and every dog in his way to verify his results. The orderly system of grouping helps him to understand the particular mechanism operating in any one group by examining a few representatives. Moreover, the biologists want to understand the interrelationship among diverse organisms. For this reason all the students of comparative biology, i.e. comparative anatomy, comparative biochemistry, enter into the domain of systematics which is essentially the study of convergence.

The names of animals differ from one language to the other and often a common name covers several types of forms. For example, if one scientist after observing the behaviour of crane at a particular corner of the globe writes "such and such behaviour was found in cranes", it does not mean anything to others. There are several types of cranes throughout the world. Anyone who has not seen that particular crane will not be able to repeat the observations and no one will be able to utilise the experience. Thus the use of common name in science simply creates confusion. The use of internationally accepted scientific names is the only prescription to overcome this difficulty.

CLASSIFICATION OF ANIMALS

The classificatory scheme of animals cannot be absolute and up-to-date, because every day new species are coming to our knowledge and adding fresh complications to the existing scheme. It is really impossible to get a thorough idea of all the varieties of animals present on the earth. Still, it is expected that the students of the subject could know at least the characteristics of major groups. The animals are usually included in eleven major *phyla* (sing. *phylum*), each presenting a well-marked and readily recognisable anatomical character. Inclusion of certain peculiar animals raises doubt and difficulties, because they possess an admixture of diagnostic features of two or more different phyla. Such an admixture of characters really makes their systematic position quite uncertain and controversial. A brief survey of the animal kingdom is given below. The detailed account of the diagnostic characteristics of each phylum and their division into respective classes, orders, etc., are dealt in greater details while describing the phyla separately. Some minor and controversial groups of animals are omitted to make the description simplified.

All animals are included under the *Animal Kingdom.* The animal kingdom is again divided into two unequal subkingdoms, *unicellular* animals and the

multicellular animals. The unicellular animals are included under the subkingdom, *Protozoa* and the multicellular animals under the subkingdom, *Metazoa*. It is believed that life at an early stage was present only at unicellular level. The origin of multicellularity arose from some unicellular stock. The animals called sponges have many cells in their body, but are not regarded to be in the direct line of multicellular ancestry by many Zoologists. Some authorities have placed them in a separate subkingdom called *Parazoa*.

Unicellular Animals (30,000 species approximately).

The unicellular animals (body made-up of a single cell only) are included in the **Phylum Protozoa** (Gr. *protos* = first and *zoon* = animal). This phylum is again

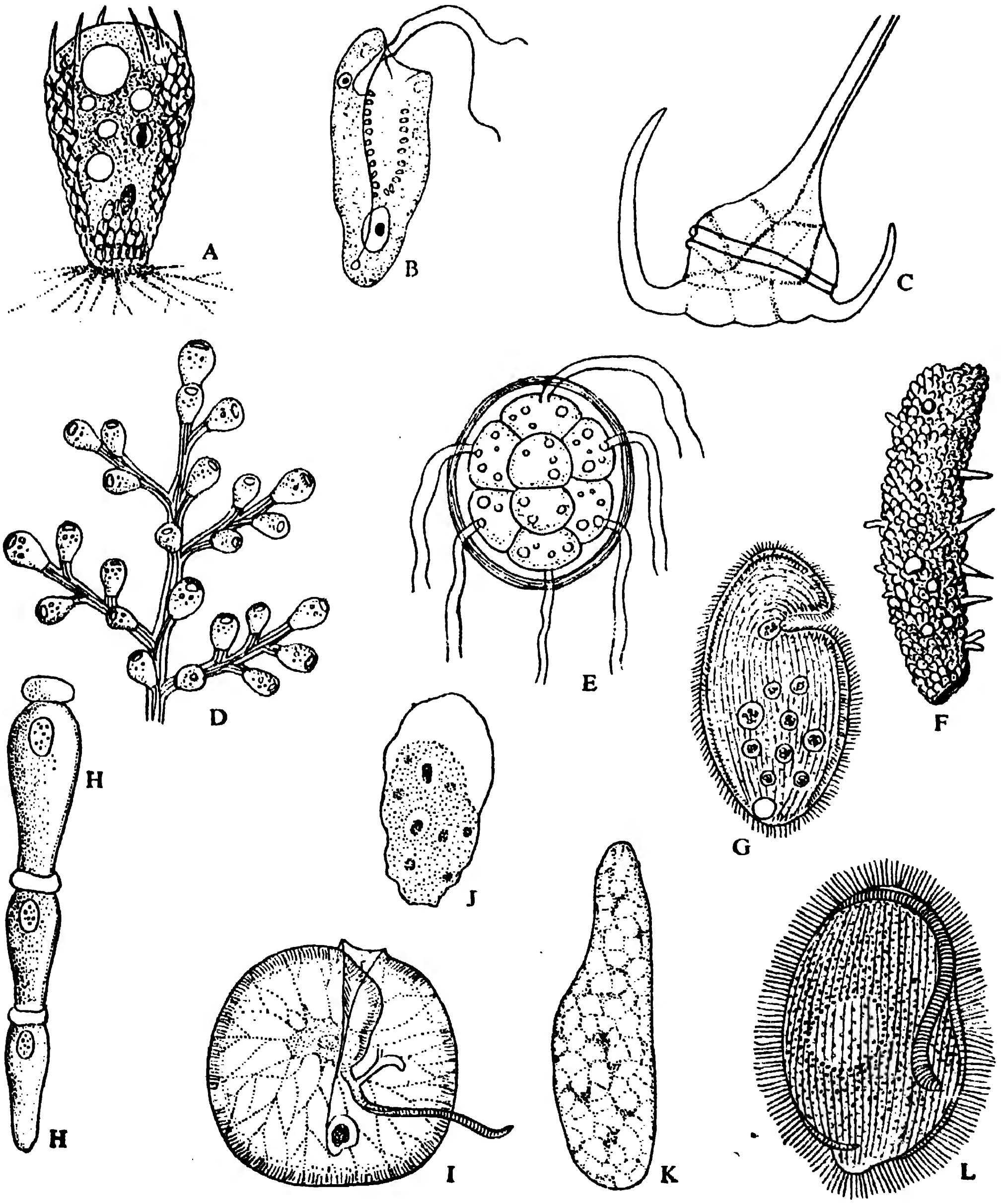


Fig. 8.4. Representatives of Phylum Protozoa. Note the variety of forms in the Phylum Protozoa (after Hyman). A. *Euglypha*. B. *Chilomonas*. C. *Ceratium*. D. *Zoothamnium*. E. *Pandorina*. F. *Saccorhiza*. G. *Plagiopyla*. H. *Gregarina*. I. *Noctiluca*. J. *Myxidium*. K. *Sarcocystis*. L. *Nyctotherus* (not drawn up to scale).

subdivided into several classes and orders. The phylum includes free living forms as well as forms which live in association with others. This phylum includes certain notable parasites causing different diseases to human beings like Malaria, Sleeping sickness, Kala-azar, Amoebiosis, etc. *Amoeba*, *Euglypha*, *Paramoecium*, *Nyctotherus*, *Euglena*, *Chilomonas*, *Noctiluca*, *Monocystis*, *Plasmodium* and *Trypanosoma*, are some of the very common examples of the phylum protozoa (Fig. 8.4).

Multicellular animals. The multicellular animals are also referred to as the metazoa (*meta*=after and *zoon*=animal). This group constitutes an informal division of the animal kingdom and this group

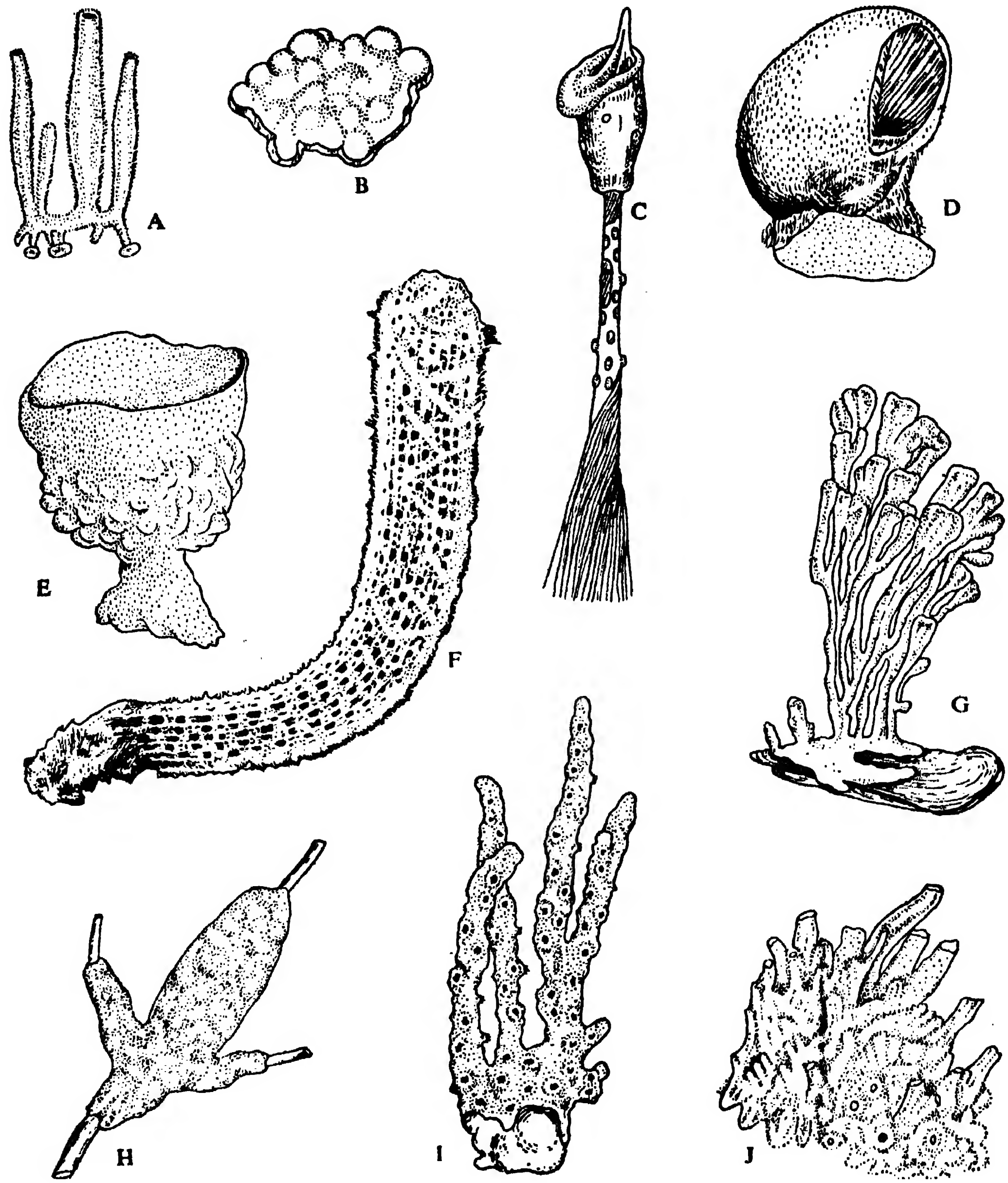


Fig. 8.5. A few examples of Phylum Porifera (after Hyman). A. *Leucosolenia*. B. *Oscarella*. C. *Hyalonema*. D. *Craniella* (A part removed to show inner radiating appearance). E. *Poterion* (Neptune's goblet). F. *Euplectella* (Venus's flower basket). G. *Microciona*. H. *Spongilla* (Fresh water sponge). I. *Haliclona*. J. *Halichondria* (not drawn up to scale).

has no taxonomic status. The inclusion of sponges under this category raises strong doubt because some authorities are of the opinion that the sponges are not to be regarded as true metazoa. They are regarded as parazoa and are considered as a blind offshoot in the pathway of metazoan origin. Multicellular animals are divided into the following phyla:

Phylum Porifera (5,000 species approximately)

The name of the phylum has been derived from Latin words and all the sponges are included in the Phylum Porifera (L. *porus* = pore and *ferre* = to bear) as the body of the sponges is perforated by pores. The organisation of sponges presents a level of multicellularity, where cells are not

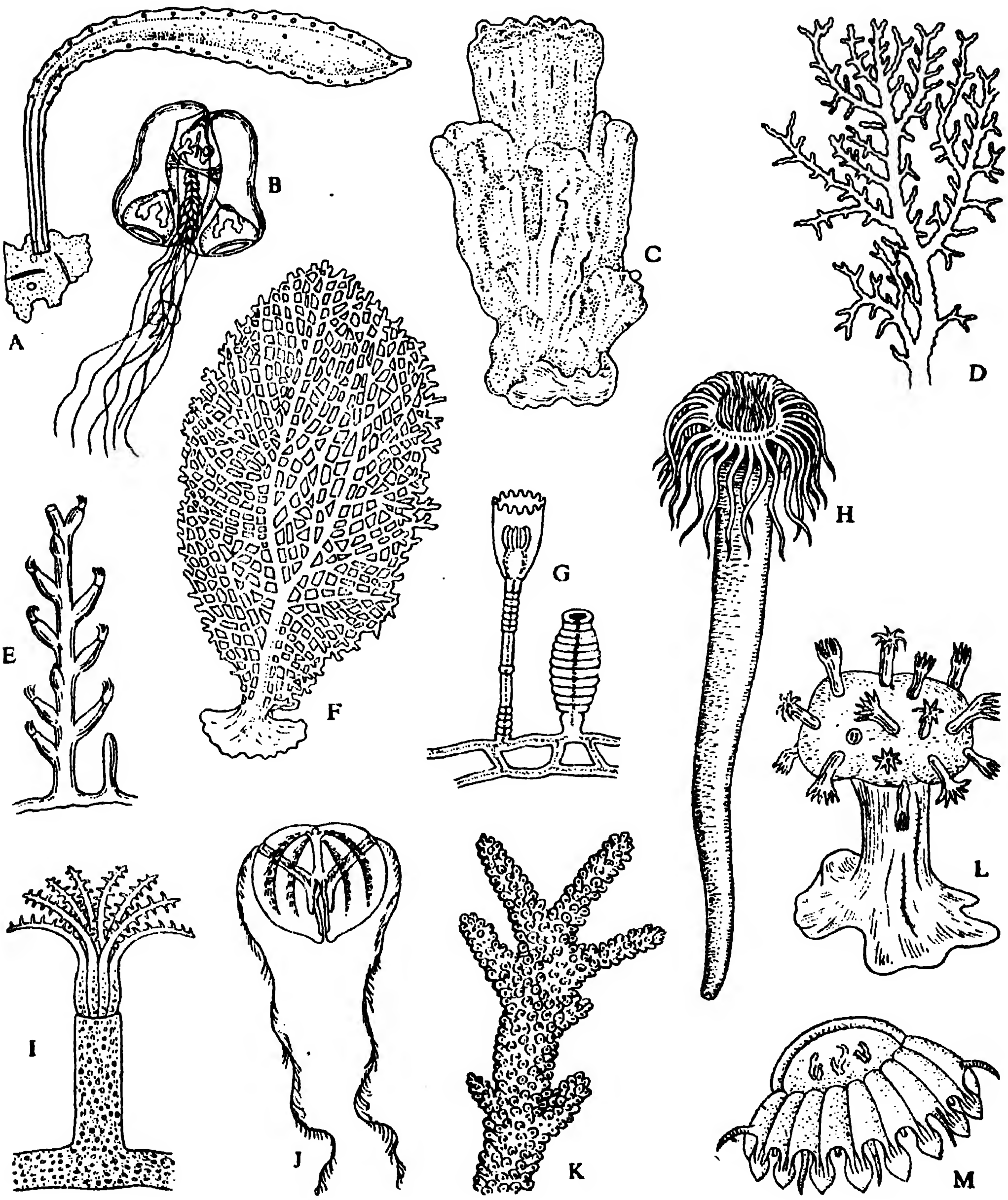


Fig. 8.6. A few members of the Phyla Cnidaria and Ctenophora (after Hyman). A. *Protohydra*. B. *Praya*. C. *Millepora*. D. *Stylaster*. E. *Telesto*. F. *Gorgonia*. G. *Clytia*. H. *Cerianthus*. I. *Clavularia*. J. *Pleurobrachia*. K. *Acropora*. L. *Anthomastus*. M. *Nausithoe*. (Figures drawn not up to scale.)

organised in definite layers. Even in such simplified state the sponges show certain specialised organisation like canal systems, spicules and gemmules. The skeletal elements are present either in the form of spongin fibres or in the form of spicules. Figure 8.5 shows some members of the phylum.

Phylum Cnidaria (10,000 species approximately)

In these metazoan forms, the cells are arranged in two layers, *ectoderm* and *endoderm* which are separated by a non-cellular strip—*mesoglea*. For this reason they are called *diploblastic* animals. In these two layers the different cells are assigned different functions. The physiological division of labour at cellular level commences from the Cnidarians. These animals possess single opening called the mouth which leads into a cavity called the

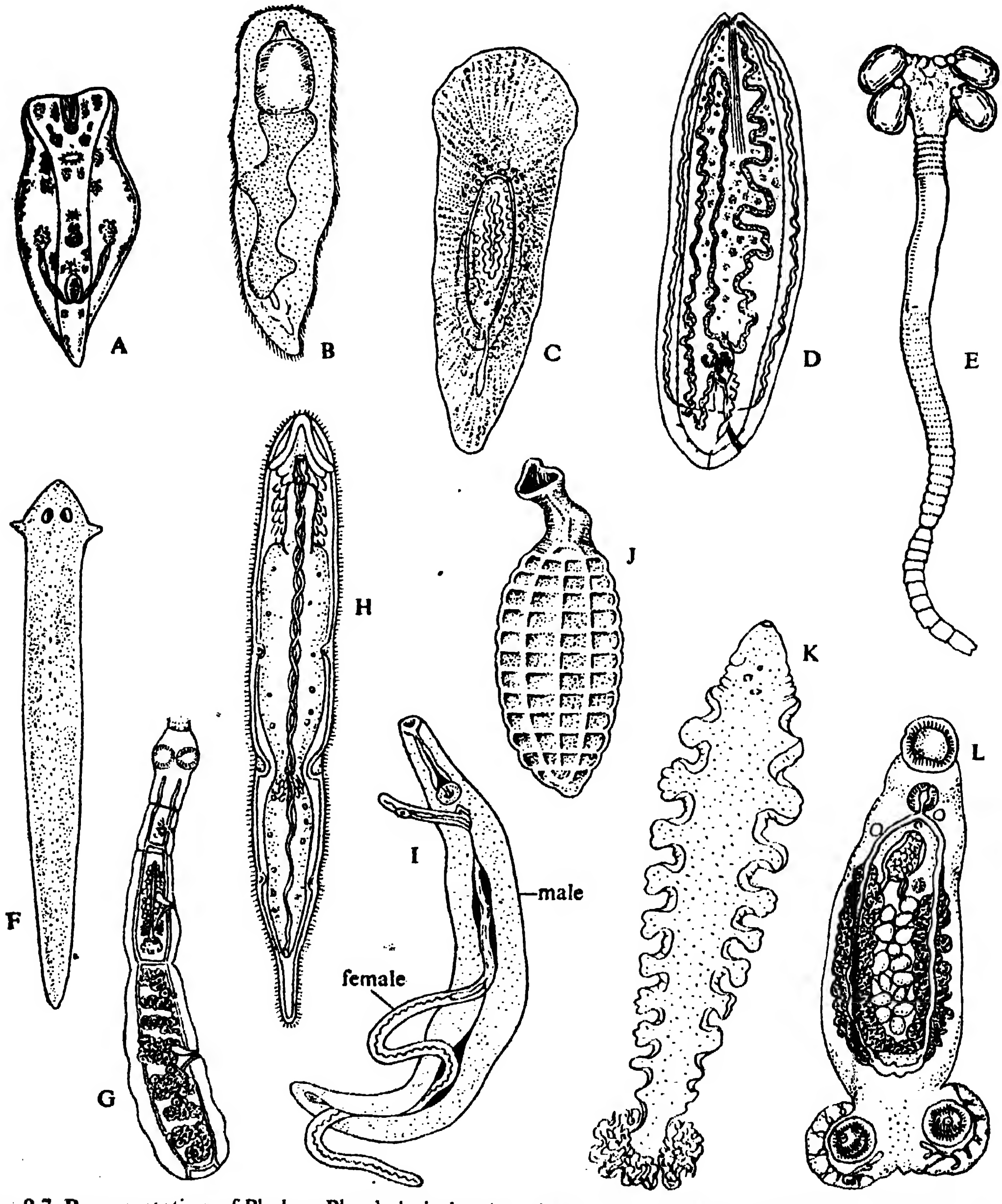


Fig. 8.7. Representatives of Phylum Platyhelminthes (not drawn up to scale). A. *Convoluta*. B. *Plagiostomum*. C. *Notoplana*. D. *Amphilina*. E. *Phyllobothrium*. F. *Dugesia* G. *Echinococcus*. H. *Stenostomum*. I. *Schistosoma*. J. *Aspidogaster*. K. *Gyrocotyle*. L. *Sphyranura*.

coelenteron (Gr. *Koilos*=hollow and *enteron* =an intestine). A special kind of cell type called *cnidoblast* is present which contains a stinging apparatus called *nematocyst*. The central position of mouth makes it possible to divide it longitudinally into identical halves, in a number of planes. Thus the members show radial symmetry. *Hydra*, *Protohydra*, *Clytia*, *Obelia*, *Aurelia*, Corals and *Gorgonia* are the typical representatives of this phylum (Fig. 8.6).

Phylum Ctenophora

The members of this phylum possess many features common to the phylum Cnidaria. This phylum is characterised by having biradially symmetrical body. The nematocysts are absent, but the adhesive cells or *colloblasts* are present. Eight rows of ciliary plates are present. A gelatinous ectomesoderm containing mesenchymal muscle fibres are present. The Phylum Ctenophora is a small group embracing about 80 species. The typical examples are *Hormiphora*, *Pleurobrachia* (Fig. 8.6J), *Beroe* and many others.

Phylum Platyhelminthes (About 10,000 species)

The members of the Phylum Platyhelminthes (Gr. *platys*=flat and *helminthes*= worm) have dorsoventrally flattened body and thus usually exhibit bilateral symmetry which means that their body can be divided longitudinally into two identical halves only through one plane. These animals possess in between ectoderm and endoderm, another cell layer called mesoderm. For this reason they are called *triploblastic*. The digestive system is either ill-developed or absent. Most of the animals are parasitic. They are mostly hermaphrodite, i.e., the same individual bears both male and female sex organs. *Planaria*, Flukes, *Taenia*, *Echinococcus*, *Schistosoma* and *Phyllobothrium* are some of the representative members (Fig. 8.7).

Phylum Nemathelminthes (About 12,000 species)

The representatives of the Phylum Nemathelminthes (Gr. *nematos*=thread and *helminthes*=worm) are called the round worms. They may be free-living or parasitic. The body is built in the plan of a tube within a tube. *Ascaris*, *Enterobius*, *Ancylostoma*, *Wuchereria*, *Trichinella* are some of the members of this phylum (Fig. 8.8).

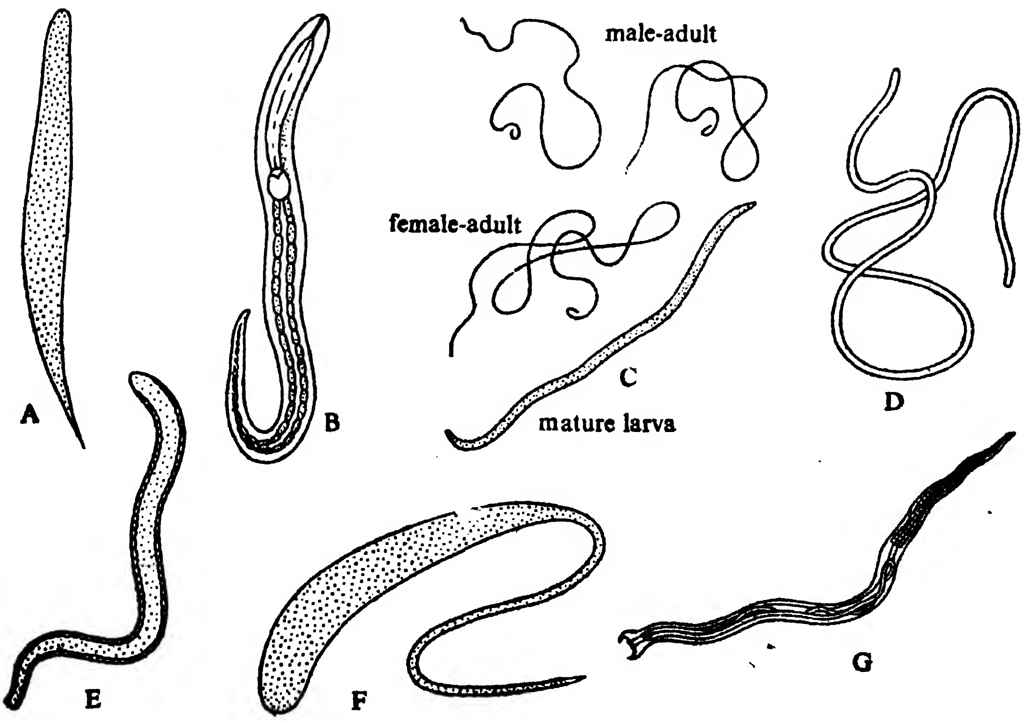


Fig. 8.8. A few examples of Phylum Nemathelminthes (not drawn up to scale). A. *Enterobius* (pin worm). B. *Ancylostoma* (Hook-worm). C. *Wuchereria* (filaria worm). D. *Loa* (eye-worm). E. *Dracunculus* (Guinea-worm). F. *Trichuris* (whipworm). G. *Trichinella* male (Trichina worm).

Phylum Annelida (About 8,700 species)

The members of the Phylum Annelida (L. *anellus* = a ring) have an elongated body. The entire length of the body is divided into a number of segments by transverse partitions. These partitions are called *septa*. The body is divided externally as well as internally. Each segment of the body is called a *metamere*. The mesoderm layer is split—one part adheres to the ectoderm called *somatopleure* and other part remains attached with the endoderm and is called *splanchnopleure*. The space in between them is called the coelom. The animals having the coelom is called the *coelomate*. The locomotor organs are usually in the form of setae. The locomotor organs, if present, are unjointed. The well-known examples are *Pheretima*, *Lumbricus*, *Aphrodite*, *Nereis*, *Eunice*, *Placobdella*, *Polygordius* (Fig. 8.9).

Phylum Arthropoda (About 891,000 species)

The Phylum Arthropoda (Gr. *arthros* = joint and *podos* = foot) includes largest number of animals. These animals are characterised by their metameric segmentation. The body is covered by chitinous exoskeleton. Paired jointed appendages are present. Cephalisation is well-marked. This group exhibits wide range of adaptive variations. *Palaemon*, *Periplaneta*, *Limulus*, *Scolopendra* and *Peripatus* are a few members of this great phylum (Fig. 8.10).

Phylum Mollusca (About 45,000 living and 40,000 fossil species)

The members of the Phylum Mollusca (L. *molluscus* = soft) have soft and unsegmented body in adult condition. The body is usually provided with a shell. Presence of a mantle covering the body is a characteristic feature. A ventral muscular foot constitutes the organ of locomotion. The examples of this phylum include *Pila*, *Achatina*, *Loligo*, *Octopus* and others (Fig. 8.11).

Phylum Echinodermata (About 5,500 living species)

The members of the Phylum Echinodermata (Gr. *echinos* = spiny and *dermatos* = skin) exhibit pentaradial symmetry. Calcareous ossicles are present in the dermis. A network of vessels through

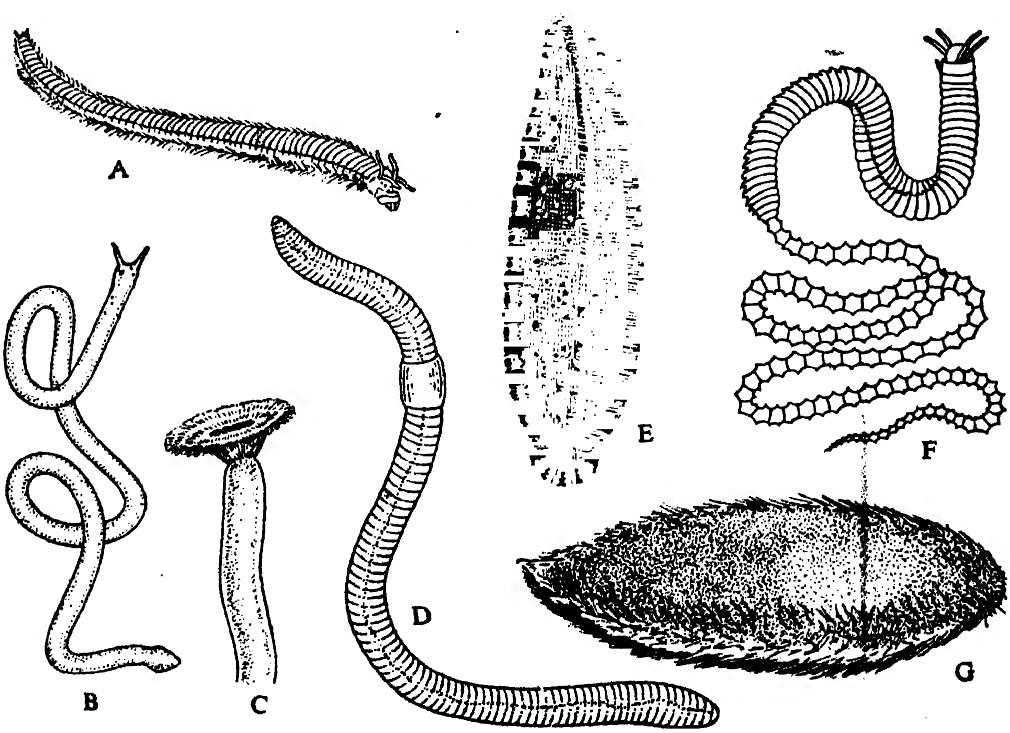


Fig. 8.9. A few members of Phylum Annelida (not drawn up to scale). A. *Neanthes*. B. *Polygordius*. C. *Bispira* (fan worm). D. *Lumbricus* (British earthworm). E. *Placobdella*. F. *Eunice* (palolo worm). G. *Aphrodite* (sea mouse).

which water flows constitute the water vascular system which is an important feature of this group. All the members are marine. The typical examples are the Starfishes, *Antedon*, *Ophiura* and *Holothuria* (Fig. 8.12).

Phylum Chordata. The Phylum Chordata (L. *Chorda*=cord) gets the name

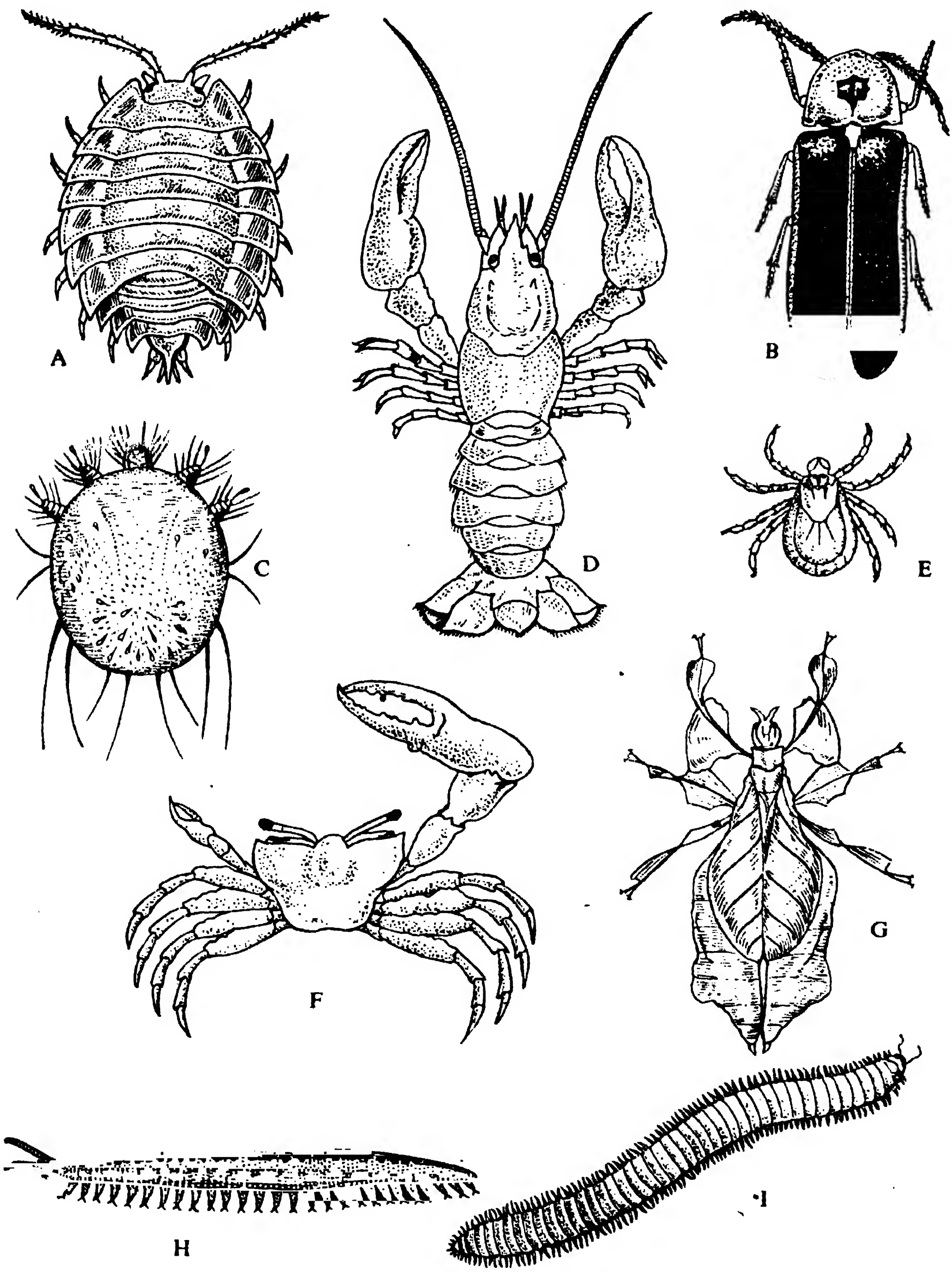


Fig. 8.10. Representatives of Phylum Arthropoda (not drawn up to scale). A. *Oniscus* (wood louse). B. *Photinus* (fire-fly). C. *Sarcoptes* (itch mite). D. *Astacus* (cray-fish). E. Tick. F. *Gelasimus* (fiddler-crab). G. *Phyllium* (leaf insect). H. *Peripatus*. I. *Julus* (millipede).

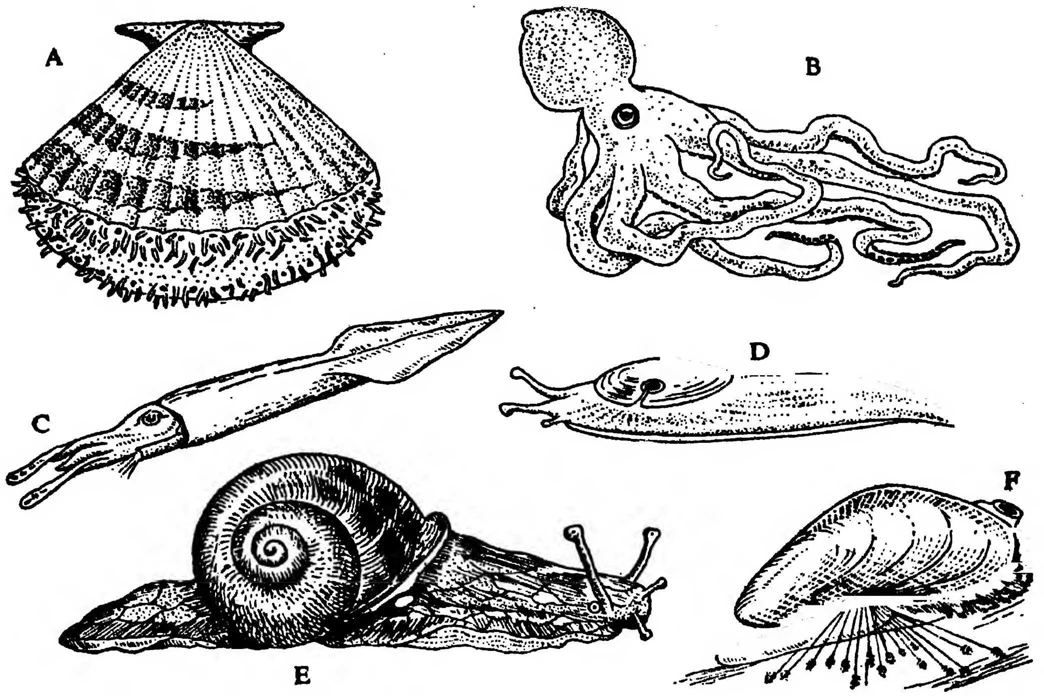


Fig. 8.11. Some members of Phylum Mollusca (not drawn up to scale). A. *Pecten* (scallop). B. *Octopus*. C. *Loligo* (squid). D. *Limax* (slug). E. *Helix* (Roman snail). F. *Mytilus* (sea-mussel).

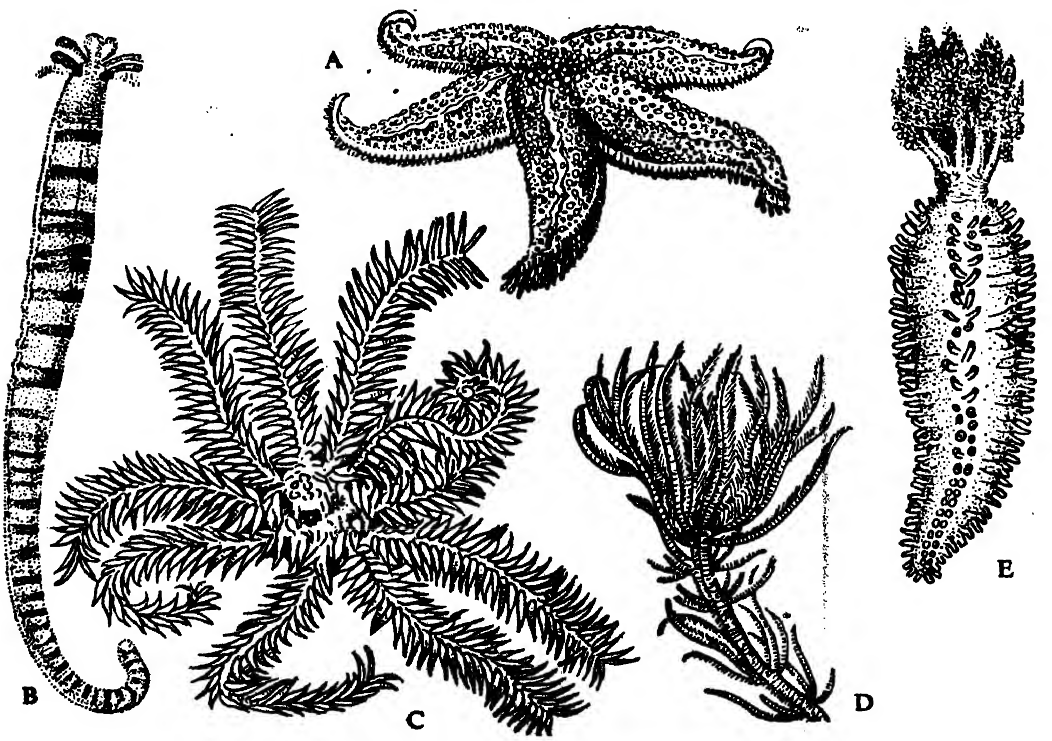


Fig. 8.12. Animals belonging to Phylum Echinodermata (not drawn up to scale). A. *Asterias* (starfish). B. *Ophsodesoma* (related to sea-cucumber but completely without tube feet). C. *Antedon* (feather star). D. *Isocrinus* (sea-lily). E. *Cucumaria* (sea-cucumber).

from the presence of notochord at some phase of development or throughout life. In case of higher forms the notochord is replaced by vertebral column. The other characteristics are the pharyngeal gill-slits, dorsal tubular nerve cord, etc. This group includes the lower chordates, e.g. *Balanoglossus*, *Molgula*, *Amphioxus* and the vertebrates like Cyclostomes, fishes, amphibians, reptiles, birds and mammals (Fig. 8.13).

Doubtful groups. There are several other animals which do not fall within

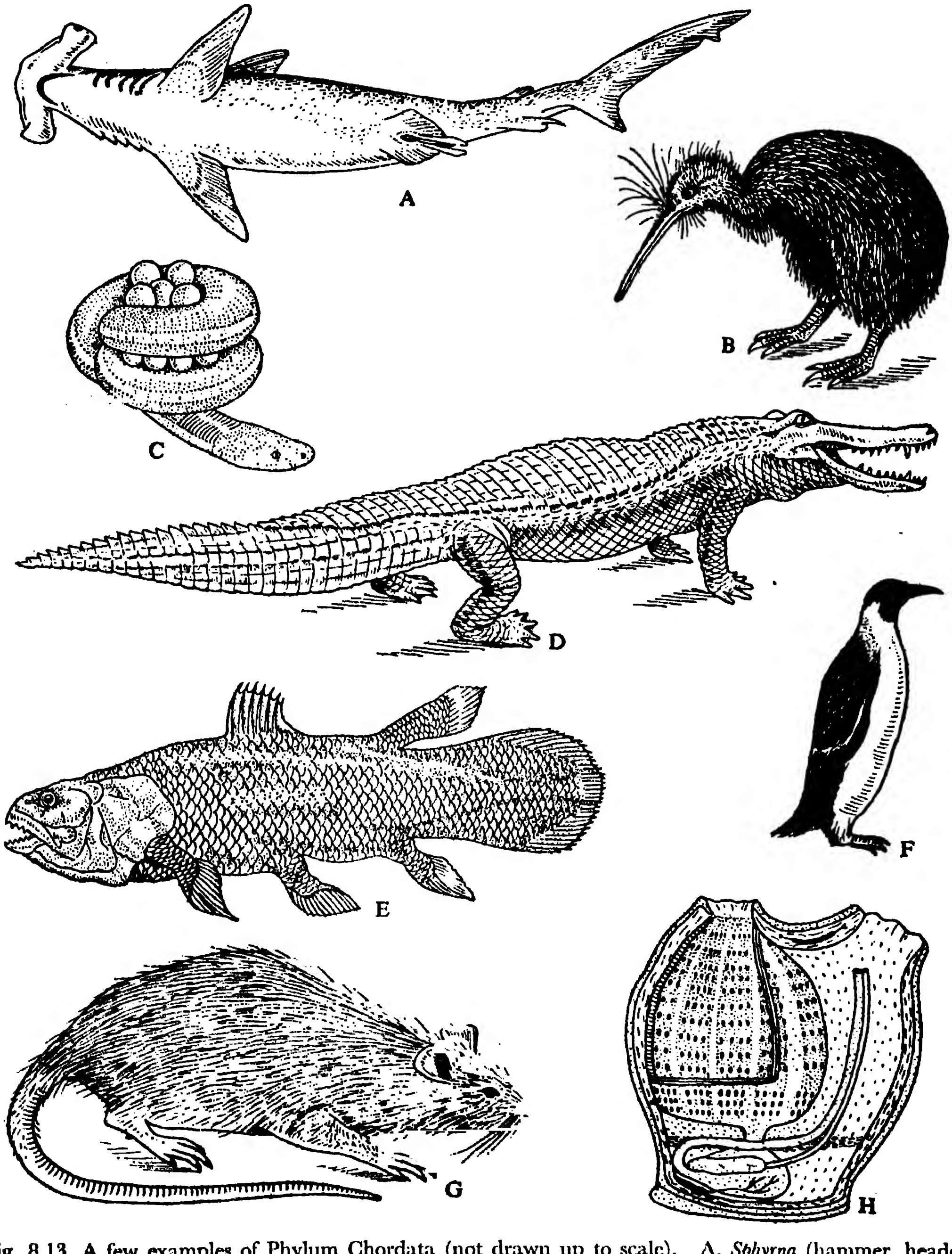


Fig. 8.13. A few examples of Phylum Chordata (not drawn up to scale). A. *Sphyrna* (hammer headed shark). B. *Apteryx* (kiwi). C. *Ichthyophis* (caecilian). D. *Alligator*. E. *Latimeria* (coelacanth). F. *Aptenodytes* (penguin). G. *Rattus* (rat). H. *Molgula* (a part of the body is removed to show internal organisation).

the above phyla. As their affinities are not well understood they are placed in separate doubtful phyla, but all of them can be broadly divided into non-coelomate and coelomate groups. Some examples are given in Fig. 8.14.

NON-COELOMATE GROUPS

Phylum(?) Calyssozoa (Endoprocta) (about 60 species)

This group includes *Pedicelline*, *Loxosoma*, *Myosoma*, *Urnatella* and others. They form a group of small sedentary animals. They are either solitary or colonial. They superficially resemble the Hydroidea and the Bryozoa. All of them are marine excepting *Urnatella*. The body is stalked, cup-like and beset with a circlet of tentacles. Overhanging the mouth there lies an *epistome*.

Phylum(?) Rotifera (about 1,700 species)

The rotifers or the 'wheel animalcules' are microscopic animals, e.g. *Brachionous*. The anterior end gives rise to a retractile *trochal disc*. A peculiar structure called *mastax* is present inside the pharynx. The body cavity is spacious and lacks epithelial lining. The excretory system comprises of a pair of nephridial tubes containing flame cells. The sexes are separate.

Phylum(?) Nematomorpha (about 500 species)

This group includes a large number of extremely elongated thread-like worms. They are free-living in the sexual stage and are parasitic in asexual stage. The examples are *Gordius* (fresh-water form) and *Nectonema* (marine form). The excretory organs are absent. The nervous system is represented by a greatly thickened pharyngeal ring.

Phylum(?) Acanthocephala (about 500 species)

This group comprises of a number of parasitic forms typified by *Echinorhynchus* and *Acanthogyrus*. They are parasitic in the intestine of vertebrates ranging from fishes to mammals. The anterior end of the cylindrical body is prolonged into a proboscis. The mouth, anus and the excretory

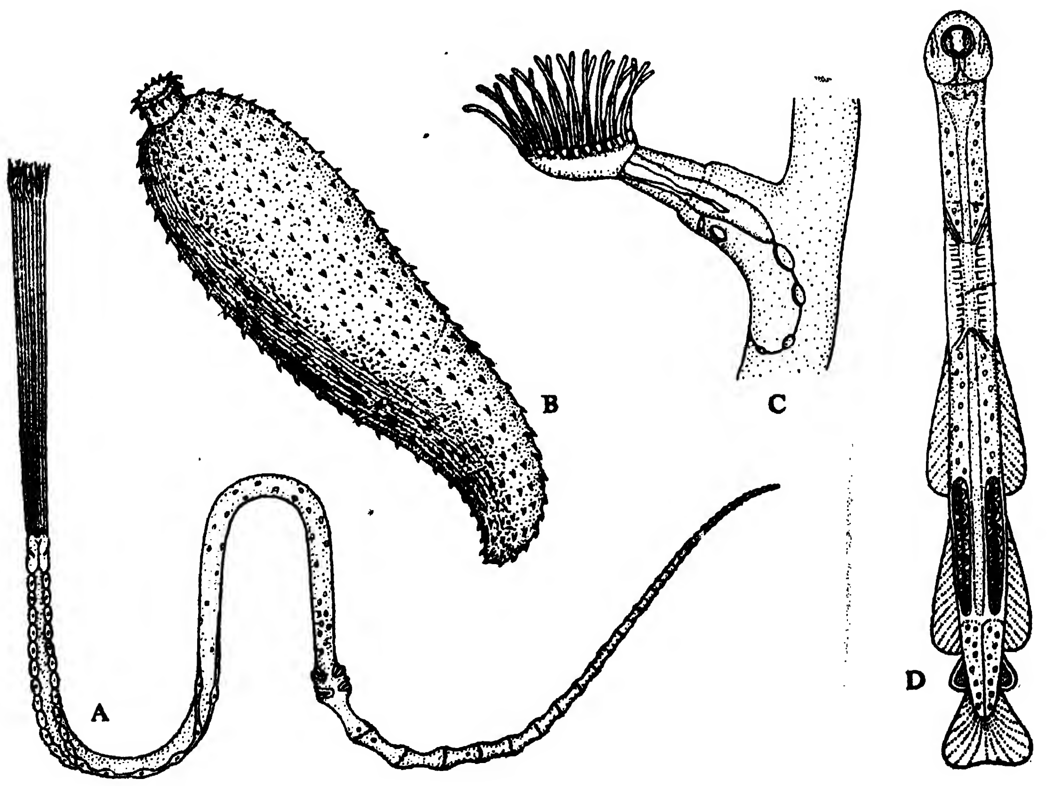


Fig. 8.14. Members of some miscellaneous phyla (not drawn up to scale). A. *Lamellisabella* (Pogonophora). B. *Acanthogyrus* (Acanthocephala). C. *Plumatella* (Bryozoa). D. *Sagitta* (Chaetognatha).

pore are absent. The digestive system as a whole is absent. Total lack of sense organs is another important feature.

COELOMATE GROUPS

Phylum(?) **Phoronida** (about 20 species)

The example of this group is *Phoronia*. They are all marine. The body is worm-like, cylindrical and unsegmented. The body is encased within a membranous tube. The lophophore is horseshoe-shaped.

Phylum(?) **Brachiopoda** (about 260 species)

The examples of the group are the lamp shells (*Lingula*). They are all marine. The shell consists of dorsal and ventral valves. Two lophophores are present. The anus may be absent.

Phylum(?) **Chaetognatha** (about 50 species)

The example of this group is *Sagitta*. They are all marine. They have small, slender and transparent body. The locomotor organs are the fins.

phylum(?) **Bryozoa (Ectoprocta)** (about 4,000 species)

The example of this group is *Plumatella*. They are branched colonial forms. The individuals are minute and are placed in separate chambers. Ciliated tentacles are present around the mouth. The digestive tract is U-shaped.

Phylum(?) **Pogonophora** (about 43 species)

The pogonophores or beard worms are very recently studied group. They have many peculiar features and show superficial similarities with the hemichordates. The examples of the group are *Siboglinum*, *Lamellisabella* etc.

SUMMARY

1. Taxonomy deals with the orderly arrangement of living forms. The *classification* part of taxonomy involves the study of characters and grouping of individuals and the *nomenclature* part includes naming and placing of the individuals in proper place.

2. Certain primary categories like *Kingdom*, *Phylum*, *Class*, *Order*, *Family*, *Genus* and *Species* have been created to establish kinship and to give systematic status to the animals.

3. An organism is given a *generic* name and a *specific* name. The generic name indicates what kind of animal it is and the name of the species explains what exact kind it is. Such scientific names are given in Latinised words and this system of naming is called *Binomial Nomenclature*. Sometimes it becomes imperative to recognise subspecies or varieties within a species giving a third specific name. Such system of naming is known as the *Trinomial Nomenclature*.

4. The animal kingdom includes eleven major phyla—PROTOZOA, PORIFERA, CNIDARIA, CTENOPHORA, PLATYHELMINTHES, NEMATHELMINTHES, ANNELIDA, ARTHROPODA, MOLLUSCA, ECHINODERMATA, CHORDATA and a few minor phyla having uncertain systematic position.

CHAPTER 9

Phylum Protozoa

By definition the protozoa are primitive animals. Morphological expression of the body of the protozoa is a single cell which contains parts within it to perform various activities that constitute the phenomena of life. These parts, called organelles though minute and simple may very well be compared to the cellular organs of metazoa whose body is made up of many cells. The cells of a metazoan body are interdependent and cannot thrive in isolation except in tissue cultures, while the single cell of the protozoa is a complete organism and is capable of independent existence. Most are so minute that a little drop of water may contain a number of them (Fig. 9.1).

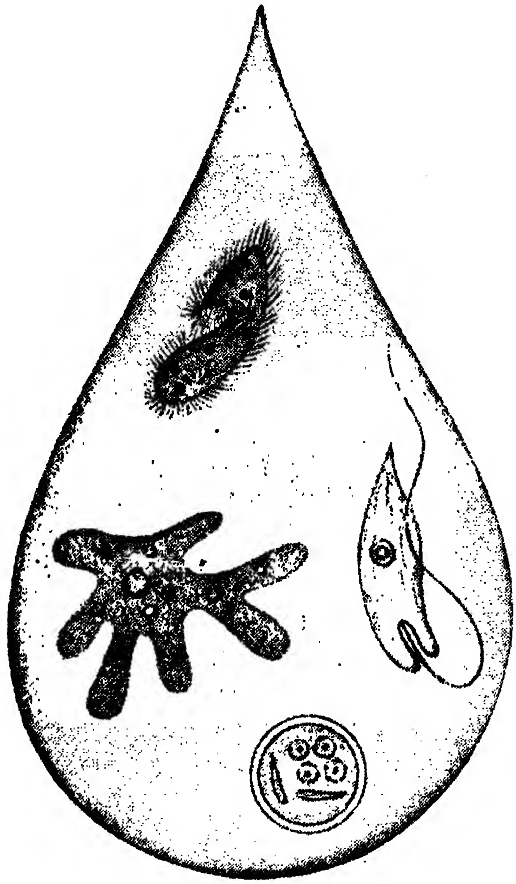


Fig. 9.1. Protozoa are so small that a drop of water may contain a number of them.

IMPORTANT FEATURES

(1) Individuals are usually microscopic, single-celled and some are colonial. (2) Body may be elongated, oval or spherical and the shape usually remains constant. (3) Single cell contains different organelles and usually one nucleus. Some forms may possess more than one nuclei. (4) Locomotion is effected either by the contractile movement of the cell or by special locomotor structures like pseudopodia, flagella or cilia. (5) Certain forms are provided with protective coverings and most of the members procreate by spores to pass through unfavourable conditions. (6) All the types of habitats—free-living,

commensal or parasitic are seen. (7) Holozoic, saprophytic, saprozoic and holophytic modes of nutrition prevail in the different members. (8) Reproduction commonly by *fission* (both binary and multiple). In certain forms sexual reproduction may occur either by conjugation or fusion of gametes.

OUTLINE CLASSIFICATION

Formerly, on the basis of their locomotor structures the phylum Protozoa was subdivided into following classes: *Rhizopoda*, *Mycetozoa*, *Mastigophora*, *Sporozoa* and *Ciliophora*. But recently the Society of Protozoologists through its committee on Taxonomy, has considered advanced cytological and microscopical findings (specially the electron microscopic observations) and has proposed new classificatory scheme of Protozoa. The detailed classification will be dealt with after describing some important examples, which belong to these groups.

EXAMPLE OF THE PHYLUM PROTOZOA—*EUGLENA*

Habit and Habitat. Several types of Euglena are well known. The type described here is known as *Euglena viridis*. It is found abundantly on the surface of fresh-water ponds. Sometimes the population of Euglena becomes so dense that water appears to be green at the surface due to the green colour of Euglena.

In the laboratory, Euglena is cultured by introducing a few collected Euglena in culture medium prepared by boiling cow or horse dung in distilled water.

Structure. Euglena is spindle-shaped in appearance. The anterior end is blunt while the posterior end is pointed. The average length of the body is about 40–65 micra by 14–20 micra. The outer limiting surface or *pellicle* is firm, elastic and gives the animal more or less a fixed shape. The pellicle is marked by delicate and spiral striations which can be seen with difficulty. Beneath the pellicle there are a few *elastic fibrils* arranged obliquely and longitudinally. The pellicle is closely followed by a *plasma membrane* on the inner side. Within the plasma membrane there lies the general mass of cytoplasm differentiated into outer *ectoplasm* and inner *endoplasm*. The ectoplasm is thin, non-granular and more 'sol' in nature while the endoplasm is granular, vacuolated and more 'gel' in nature (Fig. 9.2).

The *nucleus* is large, spherical and almost centrally situated. It lies in a clear area among the chloroplasts. Suspended in the cytoplasm there are a number of radiating *chloroplasts* containing chlorophyll. (Fig. 9.3C). The chloroplasts are elongated or ovoid in appearance. A peculiar type of animal starch called *paramylum* remains scattered in the cytoplasm in the form of grains. Sometimes the paramylum bodies show such an increase in number that they almost mask the chloroplasts. When such an Euglena is kept in darkness for several days the paramylum bodies decrease in number. Euglena, like green plants, can

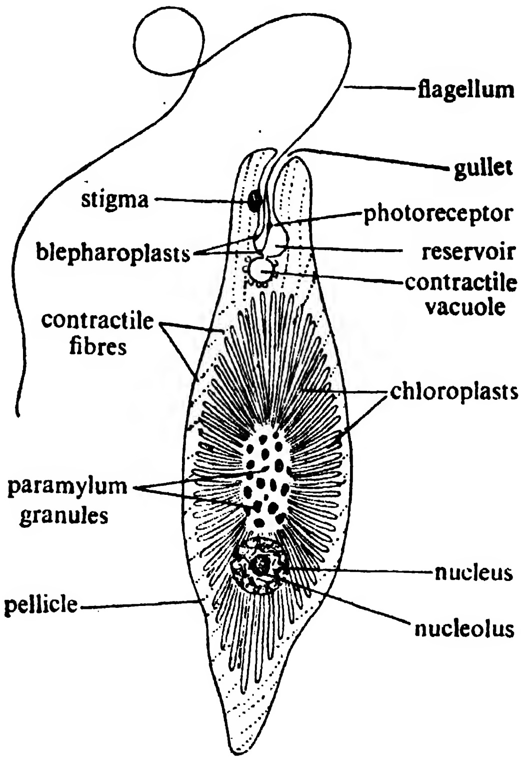


Fig. 9.2. *Euglena viridis*, note the radiating disposition of its chloroplasts.

synthesise carbohydrate food by photosynthesis. One to many *contractile vacuoles* are situated at the anterior end and in close proximation to the *reservoir* into which the products of contractile vacuoles are voided.

The anterior end bears a narrow depression—the *gullet* which leads to a flask-shaped and non-contractile *reservoir*. In the inner side of the pellicle at the gullet region there occurs a pair of *ridges* which acts as sphincter muscle. Near the base of the gullet there

is a large *pigment spot* or *stigma* (Fig. 9.3A). The stigma is bright red in colour and it is composed of small granules of carotenoid pigments embedded in colourless stroma.

A single flagellum, equal in length to the body, emerges out through the gullet. The flagellum bifurcates into two in the middle of the reservoir and the two roots go to the two compact basal granules or *blepharoplasts* situated in the cytoplasm just beneath the base of the reservoir. Some are inclined to think that there are two flagella—one short and one long. Each originates separately from the two blepharoplasts and the shorter one soon after its origin unites with the longer one. The long flagellum is thick. The flagellum is made up of two parts—an elastic axial filament—the *axoneme*, made up of several fibrils and a contractile *cytoplasmic sheath* surrounding the axoneme (Fig. 9.3B). The root of the flagellum close to the stigma bears a lens-like thickening or *photoreceptor*. Recent studies have shown that the stigma acts as a shield to the photoreceptor. When an Euglena rotates on its long axis, the presence of the stigma allows the light to strike the photoreceptor from the sides only. Euglena tries to orient itself in such a way that the photoreceptor be exposed from time to time.

Locomotion. Locomotion in Euglena is affected in the following ways (Fig. 9.4).

(*a*) **Locomotion with the help of flagellum.** The actual mechanism involved in flagellar movement is not satisfactorily known and there are varieties of flagellar movements. To explain the forward movement it has been advanced that the flagellum makes a series of lateral movements and as a result, a pressure is exerted on water at right angles to its surface. This pressure is resolved into two forces, one acting parallel and the other at right angles to the body axis. The parallel force causes the body to rotate while the force acting at right angles drives the animal forward.

Another observation states that an Euglena moves forward by the undulating motion of flagellum. A series of waves pass along the flagellum from base to tip at the rate of twelve per second. The waves proceed along the flagellum in a spiral manner and cause the body of the Euglena

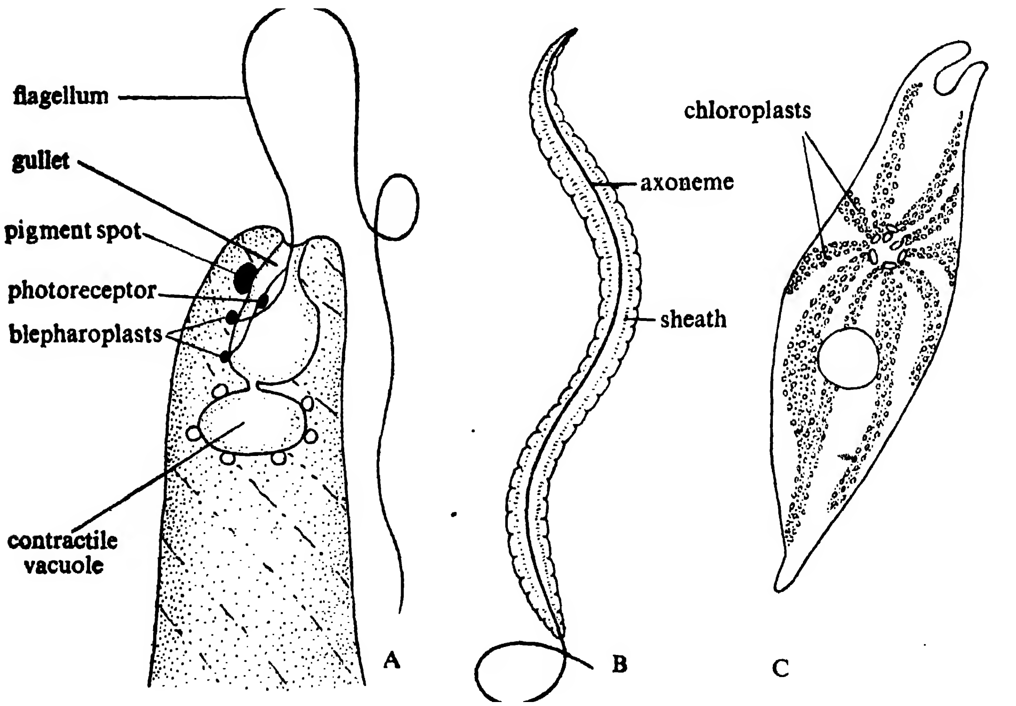


Fig. 9.3. *Euglena viridis* (after various sources). A. Enlarged view of the anterior end, B. Magnified view of flagellum and C. Arrangement of chloroplasts.

to rotate once in a second. Thus, in its locomotion it traces a spiral path about a straight line and moves forward. The rate of movement is 0·5 mm per second.

An Euglena can also move by *rowing.* While rowing the body flagellum is held rigid and is slightly arched in the direction of the stroke. In recovering the position it bends as it is drawn back to face minimum resistance.

(*b*) **Euglenoid movement.** Euglena sometimes shows a very peculiar motion in which waves of contraction pass along the body from anterior to posterior end and the animal creeps forward. The

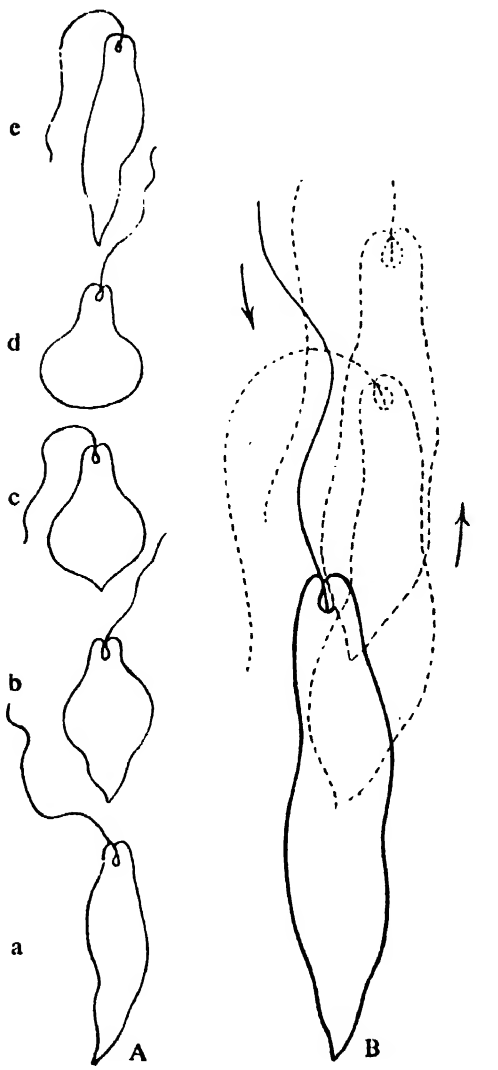


Fig. 9.4. *Euglena viridis.* Types of locomotion. A. Euglenoid movement (after Buchsbaum). B. Rowing by flagellum.

contractions are brought about by the stretching of protoplasm on the pellicle or by the localised fibrils called *myonemes* in the ectoplasm.

Nutrition. The modes of nutrition in Euglena are *holophytic* and *saprozoic.* Like a true plant it assimilates carbon and builds up carbohydrates from carbon dioxide and water. The holophytic type of nutrition occurs in the presence of sun-light and the green pigment chlorophyll plays an important role in the process. Nitrogen and other minerals which remain dissolved in pond water is absorbed by the cell surface. Excess of carbohydrates manufactured is stored as paramylum. Euglena remains an autoroph so long as it is in light and is provided with essential inorganic compounds. The whole autotrophic process in Euglena is dependent upon external sources of vitamin B_{12} which is synthesized by bacteria and some micro-organisms.

At times when pond water becomes polluted with dead and decaying organic matter Euglena gives up the holophytic mode of nutrition and switches over to a saprozoic mode. Dead and decaying matters dissolved in pond water are digested *extracellularly* and then they are absorbed through the general body surface.

Some workers have reported that small organisms are forced to enter the reservoir by the movement of flagellum and they are engulfed. Such occurrence of *holozoic* mode of nutrition in Euglena is open to doubt.

Respiration. The respiration in Euglena is aerobic. It absorbs dissolved oxygen from the surrounding medium by diffusion. In the process of photosynthesis, during day-time, a good amount of oxygen is liberated. There is every reason to believe that this oxygen is used in metabolic activities.

Excretion. The carbon dioxide accumulated in the process of respiration during day-time is used up in photosynthesis. Unused CO_2 escapes by diffusion through body surface. Nitrogenous waste matter also escapes in the same fashion.

Osmoregulation. Elimination of excess water is done by the contractile vacuole and its tributaries. The radiating or associating smaller vacuoles collect surplus water from the endoplasm and liberate their contents into the main vacuole (Fig. 9.3A), which gradually increases in size

and finally contracts to force the fluid into the reservoir. From the reservoir the fluid escapes through the gullet. Along with this, water soluble wastes are thrown out of the body.

Reproduction. Usual mode of reproduction in Euglena is *longitudinal binary fission* (Fig. 9.5). During fission locomotory activities are suspended and the flagellum some cases the flagellum of the mother is retained by one of the daughters and a new one develops in the other.

Sometimes many Euglenae come close together, lose their flagella and round up. They secrete sticky substances in which they lie embedded. This condition is called *palmella stage* which is often seen as green scum on ponds (Fig. 9.6A). Indi-

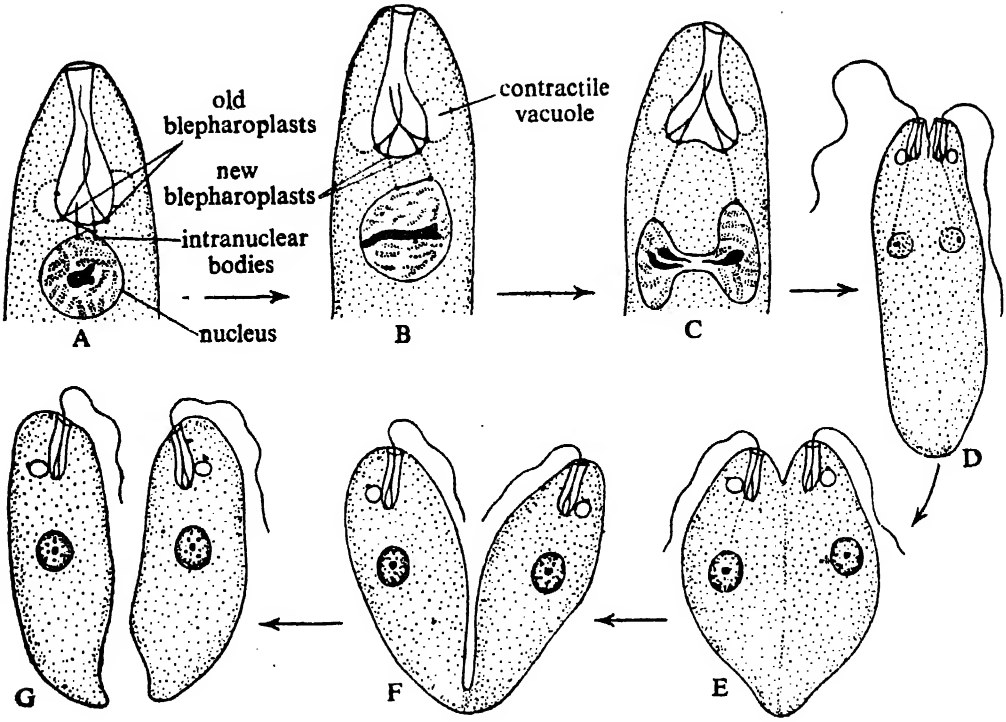


Fig. 9.5. Events during longitudinal fission in *Euglena* (from various sources).

A–C. Events at the anterior end. D–G. Formation of two daughter individuals. Note that the individual splits from the anterior end.

A. Nucleus comes to the anterior end within which intranuclear body divides into two, each of which splits to form a new blepharoplast and an intranuclear body. From the new blepharoplast develops a new flagellum. Two original blepharoplasts of the flagellum move one on each side of the reservior. Contractile vacuole divides into two. B. The new flagellum unites with the old. Nucleus descends down and connections between intranuclear bodies and newly formed blepharoplasts persist. C. Nucleus, reservoir and gullet divide longitudinally.

is withdrawn in some cases. The blepharoplast is the first to divide and the two halves remain attached by a spindle-like structure or by a strand. This is followed by *eumitotic* type of division of the nucleus. The *cleavage furrow* starts appearing from the reservoir and proceeds longitudinally to divide the animal into two. In the two daughter Euglenae regeneration of lost parts occurs immediately after division.

Each one develops a new flagellum. In vidual members of the palmella carry on metabolic activities and reproduce by fission. When favourable conditions come back the Euglenae separate, regenerate the flagella and start living normal and active life.

Encystment. Euglena *encysts* during the periods of draught and extreme cold. The animal becomes inactive, withdraws flagellum and assumes a round shape (Fig. 9.6B). Gradually, protective walls

are secreted. The cysts are red in colour due to the presence of a pigment called haematochrome.

On the return of favourable condition the cyst wall breaks and the Euglena comes out. Nuclear division may occur in encysted Euglena.

Sensitivity. Euglena shows photosensitivity and their responses vary according to the intensity of light source. Normally, it swims parallel to the light rays and towards the source of light. The stigma, together with the thickening on the flagellum constitutes a sort of *'optic organelle'* for the animal. The animal can also respond to various concentrations of chemicals, oxygen and carbon dioxide.

EUGLENA—A CITIZEN OF THE TWO KINGDOMS

Euglena bears many characters which are common to both plants and animals. Typical plant characters are the presence of chloroplast, possession of pyrenoid and occurrence of holophytic and saprozoic nutrition. While animal characters stamped in Euglena are the myonemes, contractile vacuole and the Euglenoid type of movement. However, the features like the absence of a cellulose cell wall, presence of contractile vacuole, presence of paramylum and longitudinal binary fission strongly justify its inclusion in the animal kingdom rather than in the plant kingdom.

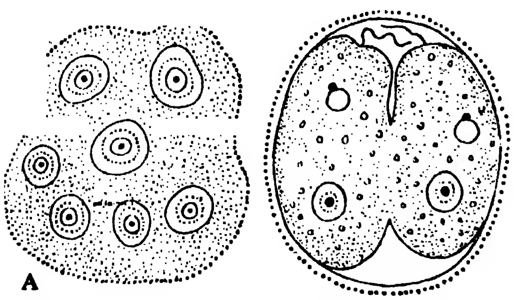


Fig. 9.6. A. Palmella stage of *Euglena*. B. Encysted *Euglena* undergoing division.

OTHER FLAGELLATES

Apart from the free-living ones a large number of flagellates are parasitic. A few parasitic forms are described below.

GIARDIA LAMBLIA. It is also known as *Giardia intestinalis* and it lives as parasite in the intestine of man and causes a disease called *giardiasis*. The distribution is cosmopolitan. Trophozoites measure 9–20 by 6–15 micra. Cytostome is absent. Protoplasm is clear. Ventral side of the body is flat and dorsal side is convex. The posterior end is pointed but anterior end is round. A bean-shaped *sucking disc* is present on the ventral surface. Two elongated nuclei and two parabasal bodies are present. There are eight rhizoplasts and flagella in following arrangements—right-1, left-1, antero-lateral-1, postero-lateral-1, ventral-2 and caudal-2. Cysts measure 8–14 by 6–10 micra and contain 2 to 16 nuclei. Infection occurs through contaminated drink or food (Fig. 9.7).

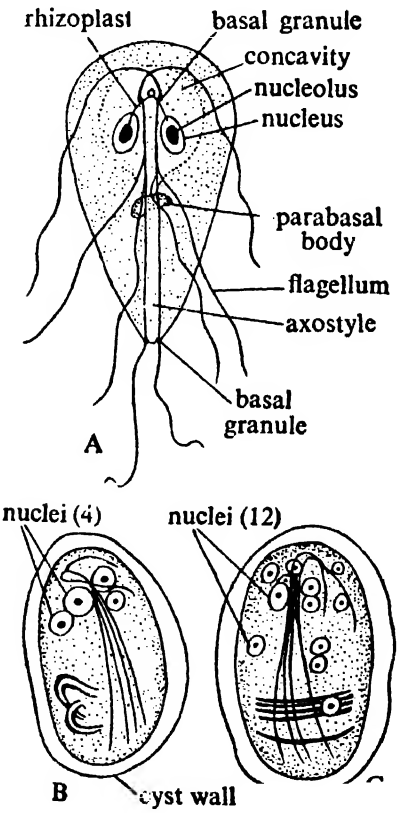


Fig. 9.7. *Giardia lamblia*. A. Dorsal view. B. Cyst with four nuclei. C. Cyst with twelve nuclei.

TRICHOMONAS HOMINIS. These cosmopolitan parasites have trophozoites of 5–20 micra and inhabit the intestine of cattle. It also lives as commensal in the colon of man. The cytostome is distinct and parabasal bodies are absent. The protoplasm contains single nucleus and food vacuoles. Number of free flagella vary

from 3–5. Two blepharoplasts are situated in front of and anterior to the nucleus. Three to four flagella arise from the blepharoplast close to the nucleus and are directed anteriorly. From the other blepharoplast arises the fixed flagellum, costa and axostyle. The fixed flagellum is accompanied by the undulating membrane throughout the whole length of the body and then continues as a trailing or posterior flagellum beyond the body length (Fig. 9.8).

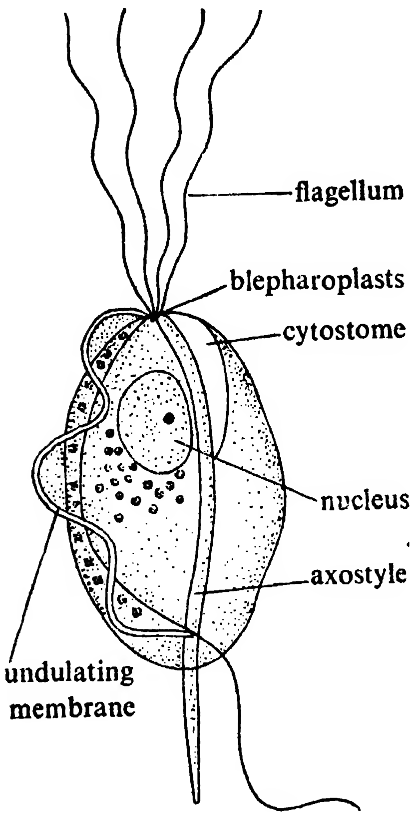


Fig. 9.8. *Trichomonas hominis*, an intestinal parasitic flagellate.

TRICHOMONAS VAGINALIS. Cosmopolitan; inhabits as a parasite in the vagina of women and also found in the urethra of man. Approximately 10–30 micra in length and more or less oval in shape (Fig. 9.9). Nucleus is elongated; cytostome is less distinct; parabasal body is large; undulating membrane is short. No cyst formation; does not survive more than 24 hours outside the body of the host. Transmission is direct through males.

HAEMOFLAGELLATES. The Haemoflagellates are a group of flagellates which habitually live in the blood or tissues of man and other vertebrates. The haemoflagellates of man belong to the family *Trypanosomatidae*. The family includes two genera namely, *Trypanosoma* and *Leishmania*. These parasites are structurally complex and are of considerable pathogenic importance to man. Trypanosomes are uniflagellated blood parasites of man and other vertebrates. They occur in variety of forms and all these forms (Fig. 9.10) are represented in the life cycle of *Herpetomonas muscarum* (a member of the family Trypanosomatidae) which is a parasite in house fly. The life cycle of Trypanosoma revolves round two hosts—one vertebrate and the other an invertebrate. The trypanosomes show polymorphism, presenting different morphological forms under different conditions. The polymorphic forms are:

I. **Leishmanial form** or **Amastigote form.** The body is round or oval with a

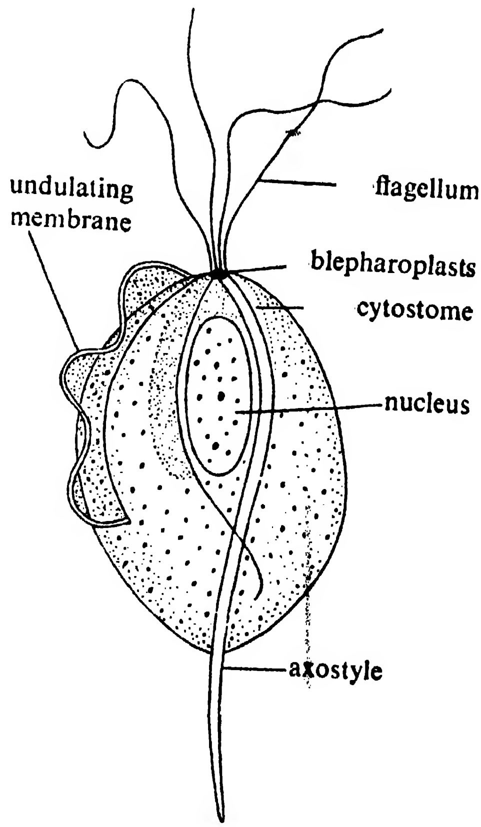


Fig. 9.9. *Trichomonas vaginalis*, a flagellate which remains as parasite in the reproductive tracts of women (after Kudo).

nucleus and a kinetoplast but no flagellum is present.

II. **Leptomonad form** or **Promastigote form.** The whole structure is thread-like, nucleus centrally located, blepharoplast is anterior to the nucleus, the rhizoplast arises from the blepharoplast and runs straight up to the anterior extremity and then emerges as a free flagellum twice as long as the body.

III. **Crithidial form** or **Epimastigote form.** The flagellum is not completely free and runs along the surface and up the anterior end. It is in association with the *undulating membrane* which is short. Beyond the anterior end the flagellum is free.

IV. **Trypanosoma form** or **Trypomastigote form.** The blepharoplast is situated behind the nucleus. Flagellum skirts the whole length of the body and remains attached to the undulating membrane.

Leishmanial forms leave the body along with the excreta of the fly. Ingestd Leishmania reaches the oesophagus of vertebrate host and is transformed into leptomonad form.

The genus *Trypanosoma* includes the typical blood parasites of man and other vertebrates. They are transmitted by the blood-sucking invertebrates from vertebrate to vertebrate. Trypanosomes occur in all vertebrates, but are pathogenic to man and some domestic mammals. The

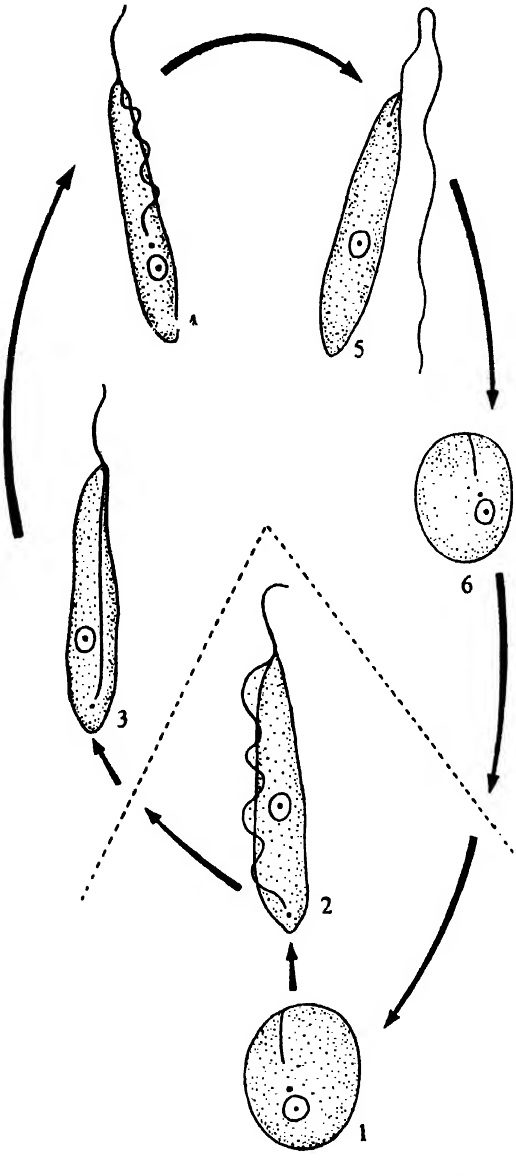


Fig. 9.10. Variety of forms in the life cycle of *Trypanosoma* (after Kudo).

1. Leishmanial form. 2. Trypanosoma form. 3. Trypanosoma form. 4. Crithidial form. 5. Leptomonad form. 6. Leishmanial form.

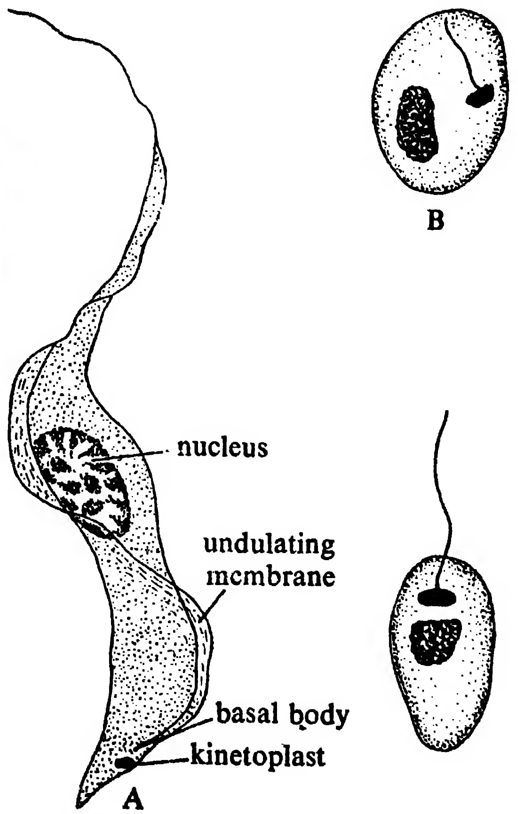


Fig. 9.11. *Trypanosoma cruzi.* A. Trypanosoma form. B. Leishmanial form 3. Crithidial form.

major pathogenic trypanosomes of man are: *Trypanosoma gambiense* and T. *rhodesiense*—the causitive agents of African sleeping sickness. The pathogenic trypanosomes have a similar life history. The biological account of some trypanosomes will give an account of the group in general.

TRYPANOSOMA CRUZI. Causative agent of *Schizotrypanosomiasis* or *Chagas' disease*. Distribution is Central and South America. Trypanosoma forms occur in the blood stream of man but do not multiply there. They are 20 micra in length and 3–7 micra in breadth. Kinetoplast is big and situated posterior to nucleus. Nucleus is elongated. Undulating membrane is narrow, free end of flagellum is not more than half the body length. *Trypanosoma forms* change to leishmanial forms and the change is reversible. Leishmanial forms are ovoid and 4 micra in diameter. Presence of distinct nucleus and rod-shaped kinetoplast, short rhizoplast perpendicular to kinetoplast may be seen. Leishmania forms reproduce by binary fission and take refuge in muscle fibres, neurons, testis, thyroid gland and skin (Fig. 9.11).

The blood-sucking hemipterous bugs of the family *Triatomatidae* are the intermediate hosts. Parasites in trypanosoma forms enter the gut of the bugs and transform to crithidial forms; several weeks after, the crithidial forms switch over to trypanosoma forms and are then called Metacyclic trypanosoma.

Man becomes infected by the deposition of excreta of bugs on the bruised skin, conjunctiva of eye and even lips.

TRYPANOSOMA GAMBIENSE. Causative agent of west African trypanosomiasis or

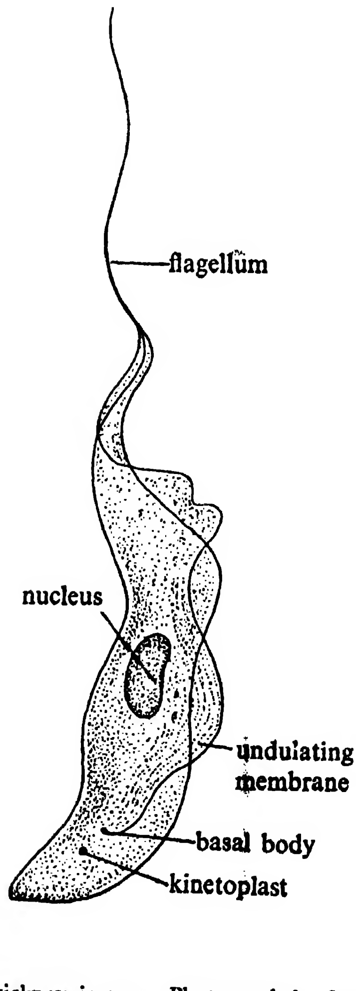


Fig. 9.12. *Trypanosoma gambiense*. It causes African sleeping sickness in man. Photograph is of a related species, *T. avium*.

sleeping sickness. They occur in the lymph glands, in reticular tissue of spleen, blood and at a later stage in the cerebro-spinal fluid in trypanosoma forms only and divide by binary fission. The trypanosoma forms are 15–32 micra in length. The undulating membrane is much convoluted, nucleus is posteriorly placed and kinetoplast is round. Cytoplasm bears volutine granules (Fig. 9.12). Three types of trypanosoma forms are known: (*i*) slender, (*ii*) stumpy, and (*iii*) intermediate.

The intermediate host is the blood-sucking tsetse fly, *Glossina palpalis*, which infects man in two ways:

(*a*) **Direct transmission.** When a fly bites a man infected with trypanosoma some trypanosomas stick to the proboscis and when this fly bites another man the trypanosomas are introduced into him provided the time between the successive bites do not exceed few hours.

(*b*) **Cyclical transmission.** When the fly takes the infecting meal the parasites enter the midgut, remain there for two days and start multiplying. To avoid washing out by the movement of gut, the parasites take refuge in the *extraperitrophic space*—the space between gut wall and *peritrophic membrane* (a thin membrane which envelops the blood imbibed by the fly) and multiply. Then they come out in huge numbers to the proventriculus after ten days and reach the salivary gland on the 12th day. They become ready for infection after 20th day.

The fly introduces the trypanosomas in the blood stream of man along its bite (Fig. 9.13).

Among the other Trypanosomas, the *Trypanosoma rhodesiense* causes east African sleeping sickness; *Trypanosoma brucei* causes nagana fever of African domestic animals and transmitted by *Glossina; Trypanosoma*

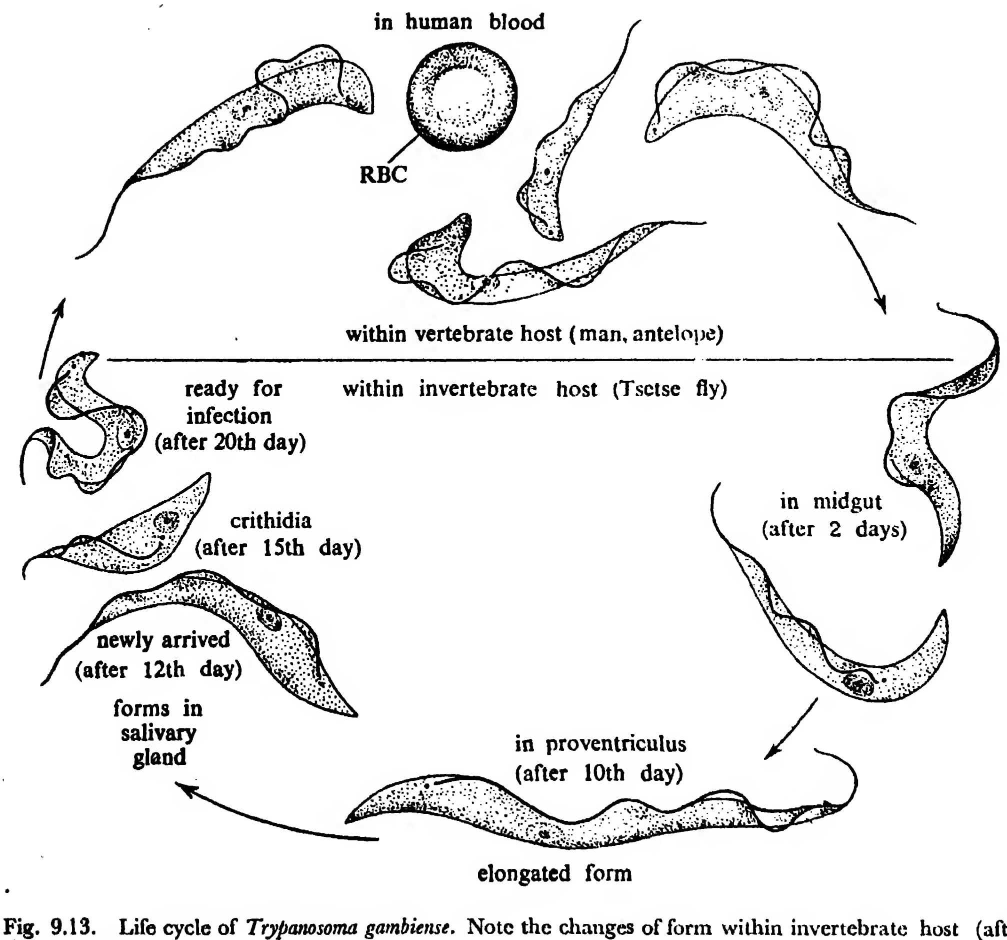


Fig. 9.13. Life cycle of *Trypanosoma gambiense*. Note the changes of form within invertebrate host (after Guyer & Lane).

evansi causing surra disease of Indian horses, cattle, camels and transmitted by tabanid flies; *Trypanosoma equiperdum* causing dourine disease of horses and mules are transmitted directly during coition. The non-pathogenic trypanosomes also occur in man. *Trypanosoma primatum* of anthropoid apes, *Trypanosoma rangeli* of man in Venezuela and Columbia and *Trypanosoma rotatorium* of frogs are some of the typical non-pathogenic trypanosomes.

LEISHMANIAS. Members of the genus *Leishmania* which are parasitic to man and other vertebrates occur in *Leishmanial forms* (flagellaless forms) and in the intermediate hosts they are seen in *leptomonad forms* (flagellated forms). Three members of the genus are parasites in man and they offer close resemblance to one other.

In man the leishmanias (Fig. 9.14) are intracellular parasites of the reticulo-endothelial system namely, the endothelial cells, large mononuclear leucocytes and Kupffer cells of liver. In case of heavy infection they have been found to invade ectodermal cells and polynuclear leucocytes.

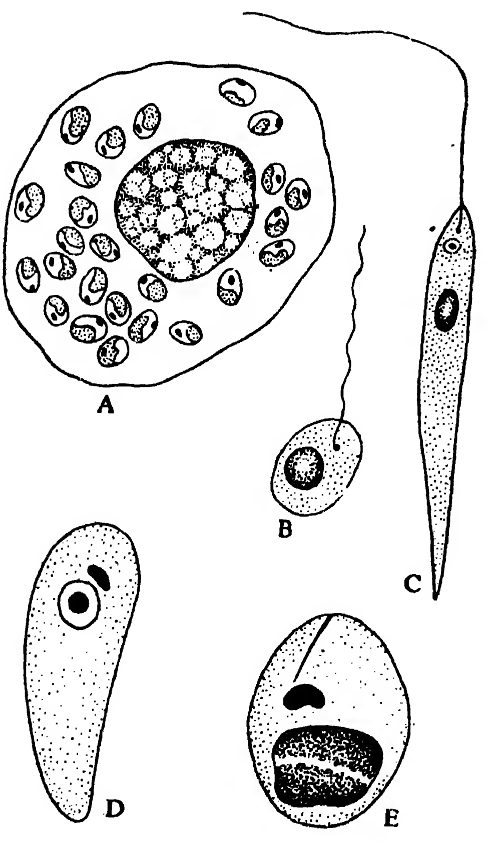


Fig. 9.14. *Leishmania donovani* (after Hall). A. Within a leucocyte. B. & C. Flagellate forms grown *in vitro*. D. & E. *Leishmania tropica* in two different forms.

Leishmanias are oval in shape and measure 2–4 micra by 1·5–2 micra. The nucleus is elongated with a rod-shaped kinetoplast which is perpendicular to the nucleus. Flagellum is absent. Binary fission is the mode of multiplication. By their successive divisions the parasites, become overcrowded in the host cell, which is ultimately destroyed.

The intermediate host is the sand fly belonging to the genus *Phlebotomus*. The fly ingests leishmanias along with the blood of the vertebrate host. In the midgut of the fly the parasites increase in size, develop flagella and are metamorphosed into long, slender *Leptomonad forms* in four days. The leptomonas multiply vigorously by binary fission and reach the proventriculus of the fly. Repeated multiplication inside the proventriculus causes complete obstruction of the organ. As a result, when the sand fly tries to ingest blood, the meal goes no further than the oesophagus. This causes a regurgitation of the sucked blood and the leptomonads are introduced in the blood stream along with the regurgitation.

LEISHMANIA DONOVANI. It resides in the viscera and is the causative agent of visceral leishmaniasis or fatal kala-azar. It is prevalent in eastern India, China, central Asia, east Africa, South America and Russia. Man becomes infected by becoming associated with a sylvatic or non-domestic reservoir jackal and domestic reservoir dog. Spreading of the disease among human being is caused by the intermediate host *Phlebotomus* (Indian vector, *Phlebotomus argentipes*).

LEISHMANIA TROPICA. Resides in human skin and is the causative agent of the cutaneous leishmaniasis or oriental boil and oriental sore. It is most predominant in the old world. Sylvatic reservoir is wild rodents and the domestic reservoir is dog. Transmission is through *Phlebotomus* (Indian vector, *Phlebotomus sergenti*).

LEISHMANIA BRASILIENSIS. It resides in the cutaneous and mucocutaneous parts of human body and is the causative agent of *Espundia*—a serious disease of buccal and nasal cavities. It is prevalent in the New-world. Sylvatic reservoir is a rodent and opossum and the domestic reservoir is dog. Transmission occurs through *Phlebotomus*.

TABLE 4—PROTOZOA

Comparison between *Trypanosoma brucei* and *Trypanosoma cruzi*

POINTS	TRYPANOSOMA BRUCEI	TRYPANOSOMA CRUZI
1. Causative agent of	African sleeping sickness.	South American sleeping sickness or Chagas' disease.
2. Distribution	Tropical Western Africa.	Central and South America.
3. Habitat	Definitive host is man and other vertebrates. In them it is essentially a parasite of connective tissue, i.e. blood and lymph where it multiplies readily. Finally it localises in the brain. Intermediate hosts are several species of fly belonging to the genus *Glossina*, where they are found in the gut.	Definitive host is man and other vertebrates. Resides in the muscular and nervous tissues and also in the Reticulo-endothelial system as amastigote forms. Mastigote forms appear in the peripheral blood at times. Intermediate host is reduvid bug like *Triatoma*.
4. Morphology	Occurs in the vertebrate host as Trypomastigote form. Trypomastigotes show polymorphism. Individual parasites vary in size and shape in the different phases of their existence. Two main forms are recognised—(1) short, thick and stumpy forms. These measure 10 μ long by 5 μ broad and without or with a short free flagellum. (2) Long, slender forms. These measure 20 μ long by 3 μ broad and possess long free flagellum. In general, T. brucei is an elongated spindle-shaped organism. The nucleus is large and centrally located. Kinetoplast is small and is situated at the posterior. The flagellum starts from the posterior end and runs beyond the anterior end as free flagellum. The undulating membrane is thrown into 3 to 4 folds.	Two main morphological forms are encountered in the human host. (1) Trypomastigote form. It measures 20 μ long by 6 μ broad. The nucleus is centrally located. Kinetoplast is large, oval and located posteriorl . (2) Amastigote form. These are round and oval bodies and are 2–4 μ in diameter. Multiplication of the parasites occurs at this stage only. Trypomastigote forms change to amastigote forms and the change is reversible.
5. Life cycle	It passes its life cycle in two hosts: 1. Development in vertebrate hosts—Metacyclic stage of Trypomastigotes introduced by the bite of Glossina (infected) develop into long and slender forms. At the site of inoculation they multiply by longitudinal binary fission and transform into	It passes its life cycle in two hosts: 1. Development in vertebrate hosts—Man becomes infected either by the faecal matter of the bug being rubbed into the wound caused by bug bite or by contamination. The metacyclic trypomastigotes invade tissue cells and transform into

TABLE 4 (contd.)—PROTOZOA

POINTS	TRYPANOSOMA BRUCEI	TRYPANOSOMA CRUZI
5. Life cycle *contd.*	stumpy forms to invade the blood stream.	Amastigote form. The amastigote forms multiply by binary fission and after passing through pro- and epimastigote stage become transformed into trypomastigote forms to be liberated in the blood stream.
	2. Development in *Glossina* (Tsetse). The short stumpy forms are ingested by the fly. In the gut of the fly the stumpy forms change to long slender forms and start multiplying for some days. After 15 days they enter the proventriculus and thence to salivary gland *via* the buccal cavity. Here they again multiply and transform to epimastigote and then again to metacyclic, i.e., short and stumpy forms of trypomastigote.	2. The trypomastigote forms enter the stomach of the bug during the act of biting. In the stomach of the bug they transform into amastigote form and multiply by binary fission. The amastigote forms transform into epimastigote form and multiply again by longitudinal binary fission. After 8–10 days they transform into Trypomastigote form and are excreted with the faeces of the bug.

EXAMPLE OF THE PHYLUM PROTOZOA—*AMOEBA PROTEUS*

Habit and Habitat. *Amoeba proteus* occurs abundantly in the bottom of pools, ponds, ditches. It is always found in association with aquatic vegetations. Successful culture of amoeba is made in the laboratory in different culture media.

Structure. The body resembles a blob of an irregular jelly and measures about 600 micra in average diameter (Fig. 9.15). The irregular shape is due to constant throwing of its own surface as *pseudopodium.*

The outer boundary of the body is made of the plasma membrane which is thin, elastic and selectively permeable. Recently, the existence of a very thin and flexible *pellicle* in amoeba has been reported and it has been possible to separate the pellicle from the plasma membrane by plasmolysis. Inside the plasma membrane are placed the nucleus and cytoplasm. The nucleus is disc-like and biconcave. The *cytoplasm* is differentiated into *ectoplasm* and *endoplasm.* The ectoplasm is less extensive, gel in the nature and nongranular though in electron microscopy it shows threads and particles of unknown significance. The endoplasm is divisible into two parts—the stiff region beneath the ectoplasm is called *plasmagel* and an

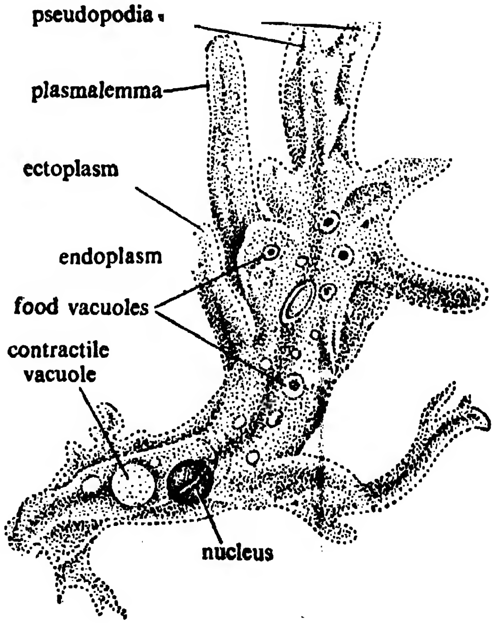


Fig. 9.15. *Amoeba proteus.* Note various structures like nucleus, food vacuoles, contractile vacuole and pseudopodia.

inner-fluid part called *plasmasol*. The plasmasol includes various organelles and inclusions. These structures are:

1. *Contractile vacuole*. Single, large and transparent; gradually increases in size and ultimately bursts.

2. *Food vacuole*. One or more spherical vacuoles containing water and food particles at different phases of digestion.

3. *Water vacuole or globule*. Several, occur as perfectly transparent colourless drops which do not change in size.

4. *Stored food*. Numerous granules of the nature of fats and carbohydrates which are recognised by using special staining methods.

5. *Mitochondria*. These are present in the form of rods or dots and are recognised by special stains.

6. *Crystals*. Crystals of assorted sizes and shapes are seen which are probably metabolic wastes.

The role played by the above-mentioned structures is given below:

Plasmalemma. It retains the inner content and is permeable to respiratory gases and water. It plays important part in pseudopodia formation and food capture.

Ectoplasm. It is responsible for maintaining the shape and also protects the inner parts.

Endoplasm. It houses different organelles including the nucleus. The conversion of plasmasol to gel and back is important in the process of pseudopodia formation.

Nucleus. It regulates the working of all other organelles and takes part in reproduction.

Contractile vacuole. It is involved in osmoregulation, respiration and excretion.

Food vacuoles. These organelles are meant for nutrition.

Water vacuoles. Numerous small water vacuoles control the water balance of the body.

Mitochondria. These bodies are regarded as the 'power house' of the cell and are the seats of cellular respiration.

Various inclusions. It includes reserve food materials and also different metabolic wastes.

Locomotion. Locomotion in amoeba is creeping in nature and is dependent upon an intimate and direct contact with as ubstratum. Creeping in amoeba involves the production of finger-like projections called the **pseudopodia** and the movement is called **amoeboid movement.** During locomotion in *Amoeba proteus* one or more blunt finger-like pseudopodia are formed in the direction of movement. The projection grows more and more by accumulation of cytoplasm from other parts of the body.

In some cases Amoeba has been seen to walk on the tips of the pseudopodia. A good many theories have been advocated to explain the mechanism involved in the formation of a pseudopodium. Mast has given a thorough and detailed description of pseudopodia formation (Fig. 9.16). According to Mast the body of the amoeba is made up of four parts—the thin and elastic plasma membrane, the plasmagel, the plasmasol and a hyaline fluid in between the membrane and plasmagel. Actions and interactions between these four parts result in pseudopodium formation.

During the formation of a pseudopodium the plasma membrane gets attached to the substratum. A local and partial liquefaction occurs in the plasmagel at a point. The rest of the plasmagel exerts pressure on the weakened area to produce a bulge. This pressure comes from osmotic and other forces. Posteriorly, the contracting plasmagel converts into plasmasol. Anteriorly, the plasmagel tube is continuously regenerated by gelation of plasmasol and the pseudopodium grows.

Thus the formation of pseudopodium and the resultant movement in amoeba are due to spontaneous and reversible sol-gel phenomenon.

Nutrition. Amoeba is holozoic in nutrition and feeds on unicellular plants or animals such as bacteria, diatoms, small ciliates and tiny algal filaments. It has the capacity to discriminate between nutritive and non-nutritive food. It has been shown that an amoeba can discriminate between *Chilomonas* and *Monas* and shows preference for the former.

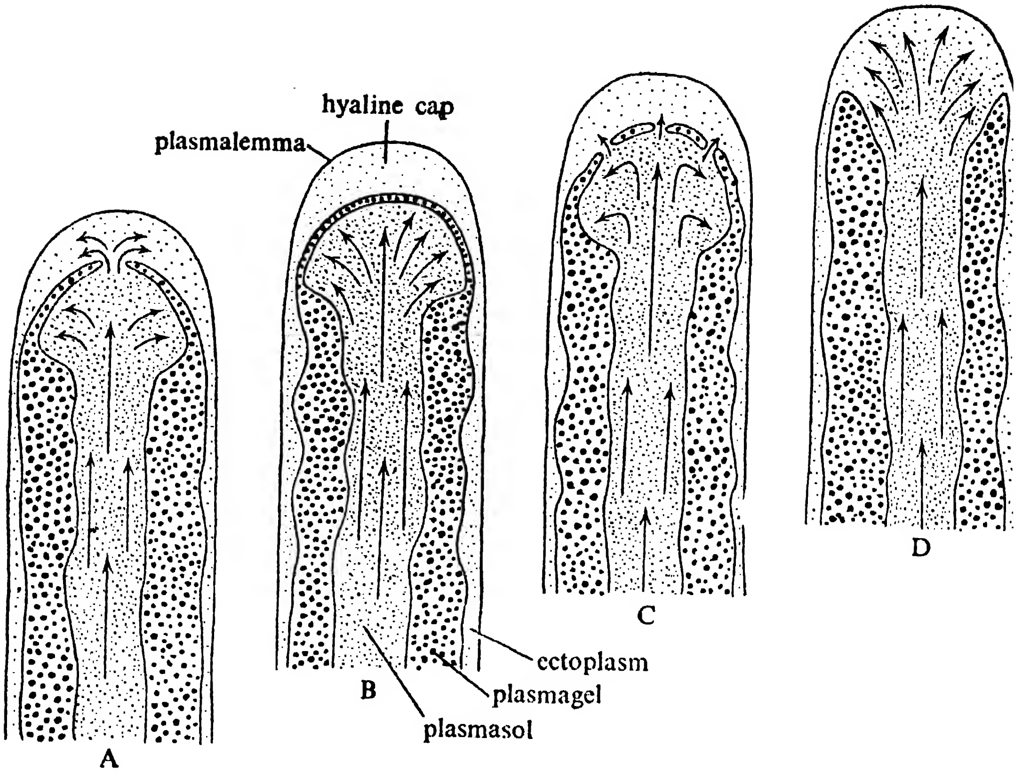


Fig. 9.16. Figures illustrating the idea of Mast about the cytoplasmic flow during the formation of a pseudopodium in *Amoeba proteus* (after Kudo). Note that during the formation of a pseudopodium a hyaline cap appears. A. The plasmagel beneath the cap dissolves and plasmasol rushes through the gap. B. The plasmagel may persist as a thin layer. C. Break only at certain points. D. Dissolve completely.

Amoeba often chases its food for a considerable distance (Fig. 9.17). When it comes in contact with the food particle, it extends pseudopodia on either sides and above the particle and forms a concavity or *food-cup*. Ultimately, the pseudopodia bend around the particle and their ends meet and fuse. The food particle along with some amount of water becomes enclosed in the food vacuole. The margin of the food-cup exerts sufficient force as indicated by the 'biting' of the prey into two parts. The whole process of ingestion takes about 2–3 minutes and several food vacuoles may be present at a time.

Digestive processes now start in the food vacuoles. The cytoplasm surrounding the vacuoles secretes *HCl* which kills the prey and makes the medium acidic which soon becomes alkaline as *enzymes* are secreted. Among the enzymes pepsin and trypsin have been distinguished in amoeba. The end products of digestion which are proteins, carbohydrates and fats in simple form and some soluble minerals are absorbed by the surrounding cytoplasm.

Egestion or throwing-out of non-digested food particles is done through temporary openings in the ectoplasm at a spot near the food vacuole. Figure 9.18 illustrates the process of ingestion and egestion. A process called pinocytosis or 'drinking' has been reported in *Amoeba proteus*. Pinocytosis involves the formation of a narrow canal on the surface of the body by invagination and then the pinching-off of the canal containing fluid. The importance of pinocytosis is yet to be evaluated.

Respiration. Oxygen dissolved in water enters the body through the general body surface and carbon dioxide produced by oxidation goes out through the body surface by the process of diffusion.

Excretion. By-products of dissimilation are urea and uric acid. They, along with excess salt in solution, pass out of the body through plasmalemma by a physical process called diffusion.

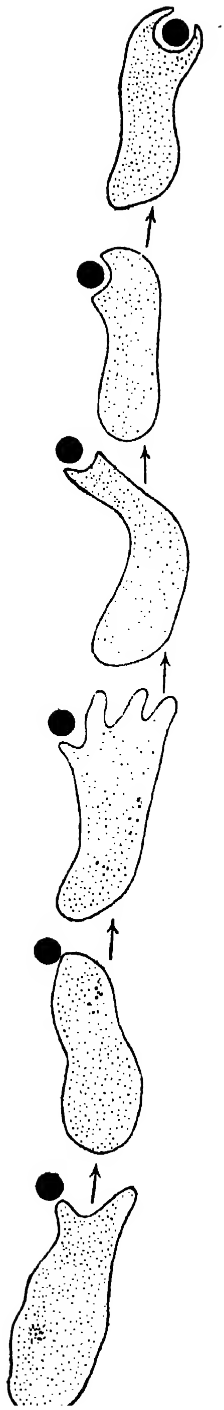


Fig. 9.17. *Amoeba* chasing food. Note constant formation of pseudopodia towards the direction of the food.

Osmo-regulation. Excess of water which enters the body through body surface and during food-intake is collected by the contractile vacuoles. A contractile vacuole is about 30–50 micra in diameter and contains accumulated fluid which is less dense than the surrounding cytoplasm. A fully formed vacuole contracts and the fluid is forced out through the cell surface. The disappearance of one vacuole is followed by the production of a new one. The rate of contraction of a vacuole varies from a few seconds to several minutes. The vacuolar activity increases when distilled water is injected and stops when the animal is put in sea water or is treated with potassium cyanide. Water discharged to the exterior by vacuoles contains traces of metabolic wastes and respiratory gases.

Reproduction. Reproduction in amoeba is asexual and is effected by *Binary fission.* The nuclear division is eumitotic type, i.e. there is distinct chromosome formation but the presence of 500 to 600 chromosomes makes the mitotic picture obscure. It has been shown that there is a definite correlation between the stages of nuclear division (Fig. 9.19) and the external morphological changes (Fig. 9.20). During prophase the animal becomes round, studded with fine pseudopodia and under reflected light presents a well-defined hyaline area at the centre. The hyaline area disappears in metaphase. During anaphase the pseudopodia become coarse and in telophase the body elongates, cleavage furrow appears and gradually the pseudopodia return to normal structure.

Encystment. Encystment in *Amoeba proteus* has not yet been reported though it is a very common feature in other amoebae (Fig. 9.21).

In extremes of coolness or hotness and in other unfavourable conditions an amoeba encysts. During encystment the body becomes round and the pseudopodia are withdrawn. The food particles are either absorbed or thrown out and the contractile vacuoles disappear. The cytoplasm secretes a double-walled resistant envelope around it (Fig. 9.22).

On the return of favourable condition excystment occurs. The protoplasm inside the cyst comes out by breaking the cyst wall at a point,

The cyst in case of amoeba is protective in nature and not reproductive. Evidences in favour of amoeba undergoing nuclear division in encysted condition are very rare. It is to be noted that one amoeba comes out of one cyst.

Entamoeba histolytica has been recorded from Orang Utan, Gorilla, Chimpanzee, Gibbon, Baboon, Monkey, Dog, Cat, Rat and Pig.

The parasite is worldwide in distribution and the disease caused by the parasite is known as 'Amoebic dysentery', the medical importance of which is well established.

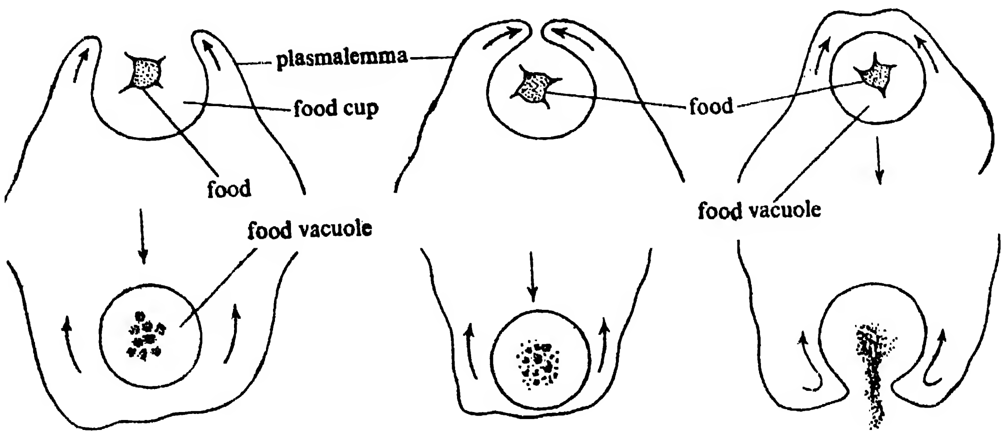


Fig. 9.18. Mechanism of Ingestion (upper row) and Egestion (lower row) in *Amoeba*. Note that during ingestion a part of plasmalemma is cut off to be the lining of food vacuole. During egestion the same membrane again becomes continuous with plasmalemma.

Sensitivity. An amoeba gives negative response to mechanical obstacle. When it is pricked or touched by a rod it turns to avoid the obstacle. However, it can distinguish between a particle of no use and a particle of food. It readily repels itself from salt, sugar, acid and alkali as it is unaccustomed to them. Amoeba shows negative reaction to strong light and positive reaction to gravity. The responses of amoeba are so oriented as to benefit the individual to the maximum.

Example of the Phylum Protozoa—
ENTAMOEBA HISTOLYTICA

The genus *Entamoeba* was established in 1879 by Leidy. *Entamoeba histolytica* was first described as *Amoeba coli* by Losch in 1875. Schaudinn established the species *Entamoeba histolytica* in 1903 and differentiated the pathogenic and non-pathogenic types.

Entamoeba histolytica is a parasite that inhabits the mucous and submucous layers of the large intestine of man. It may also occur in the liver, lungs and rarely invades brain, spleen, etc., producing ulcers.

Morphology. (*a*) **Trophic.** The trophozoites vary in size from 15 to 40 micra, the average being 18 to 25 micra. Dobell (1919) and others have shown that the parasite has got two races, one large and the other small. The trophozoite of *Entamoeba histolytica* in living condition shows two distinct portions, ectoplasm and endoplasm. The ectoplasm is clear and translucent while the endoplasm is granular. The endoplasm often contains injested red blood corpuscles. The pseudopodia may be long, finger-like or short and rounded in shape (Fig. 9.23). In freshly passed stool the parasite is very active and moves rapidly in a straight line with a single clear pseudopod at the anterior end. This is known as 'directional movement'. The movement becomes sluggish when the faeces cool down and in this condition the amoeba throws out pseudopodia at various directions and remains stationary.

The nucleus is indistinct in living condition but when stained with haematoxylin it shows a small dot-like central

karyosome or endosome, a uniform ring of small peripheral chromatin granules and at times some chromatin granules in between them. Sometimes there may be traces of *linin network* in the form of fine

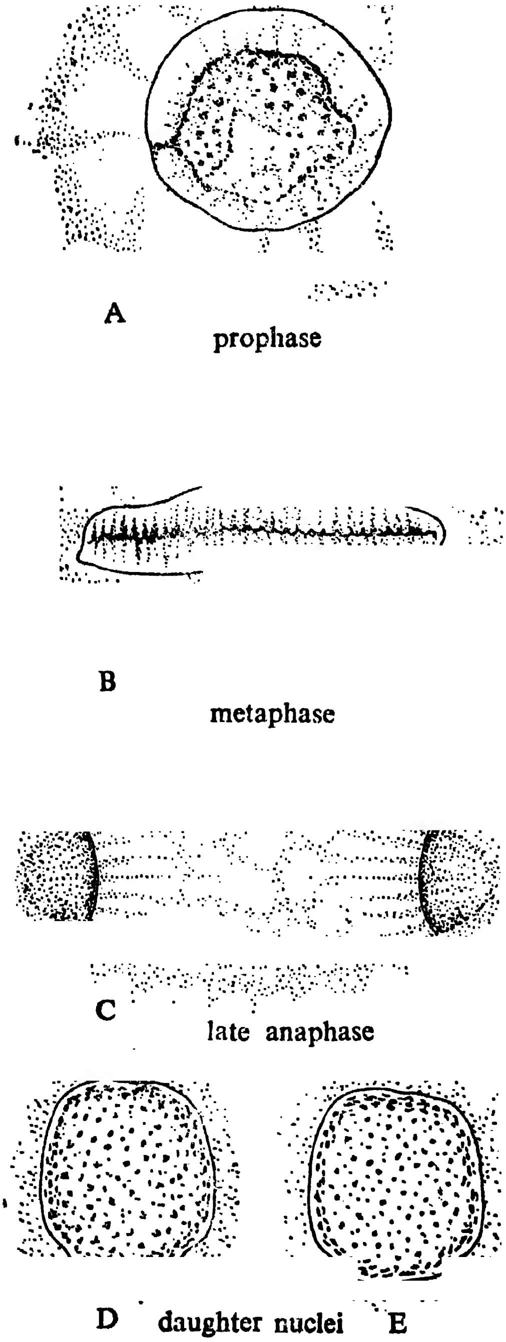


Fig. 9.19. Changes in the nuclear apparatus during the binary fission of *Amoeba*.

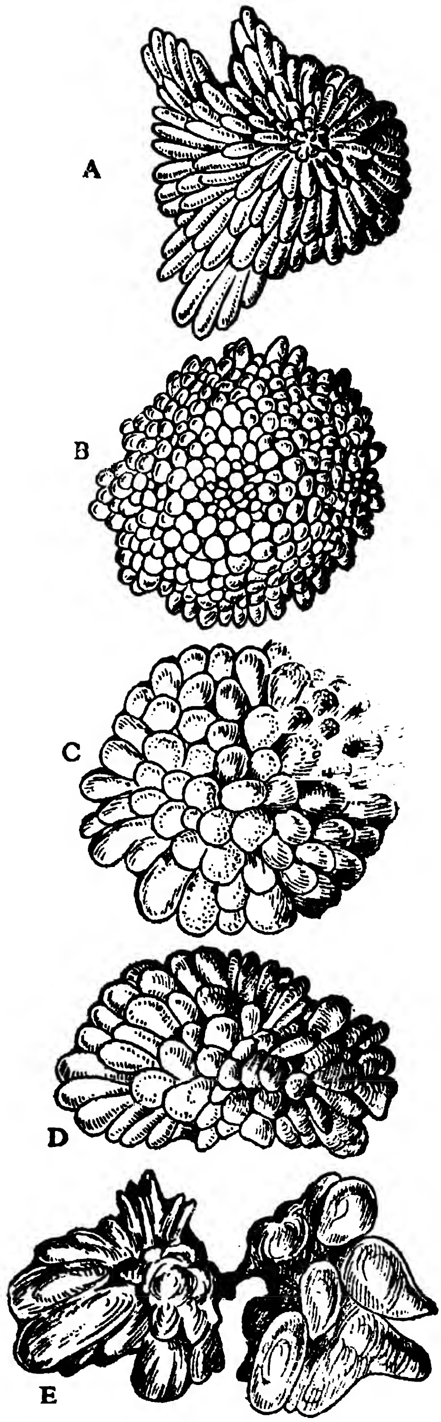


Fig. 9.20. Morphological changes in *Amoeba proteus* during binary fission (after Kudo). A. In prophase. B. & C. In metaphase. D. In late anaphase. E. In telophase.

fibrils in between karyosome and nuclear membrane. The nuclear membrane is very delicate. The size of the nucleus is about 4 to 6 micra in diameter.

Fig. 9.21. A. Trophic and B. Cyst of soil Amoeba, *Acanthamoeba* sp. (Courtesy of Dr. S. Mookerjee).

(*b*) **Cystic.** The cysts of both races of *Entamoeba histolytica* vary in size from 10 to 20 micra (average 12 micra) in diameter. In haematoxylin stained preparation a matured cyst looks spherical and quadrinucleate. Its cytoplasm is clear and often contains black rod-like chromatoid bars or bodies with rounded ends (Fig. 9.23D).

The young cysts are uninucleate or binucleate and their nuclear structure is just like that of the trophozoites. But the

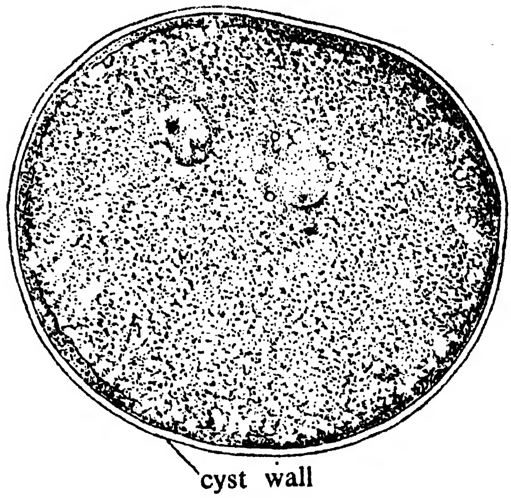


Fig. 9.22. Encystment in Amoeba (after Winchester). Although very common in other Amoebae, it rarely occurs in *Amoeba proteus*.

nucleus of a matured cyst is very small and its detailed structure is difficult to differentiate, particularly of the small race. It

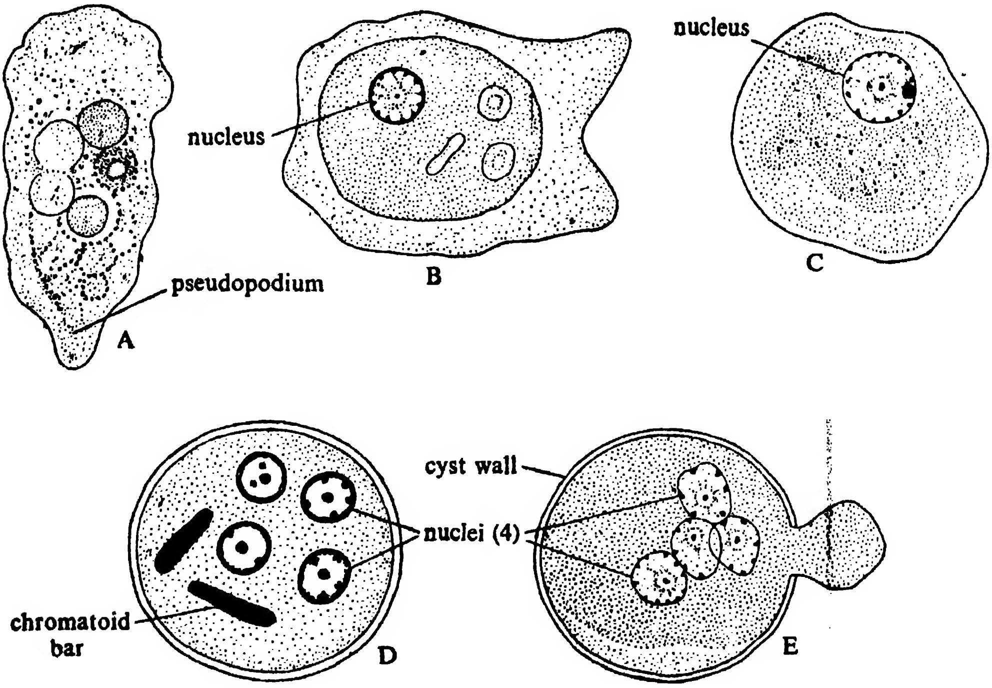


Fig. 9.23. *Entamoeba histolytica* (from various sources). A. Living trophozoite. B. Stained trophozoite. C. Precystic stage. D. Cystic stage. E. Excystment.

shows a very small central karyosome and a delicate nuclear membrane.

Presence of chromatoid bodies is the characteristic of the cysts of *Entamoeba histolytica.* They occur either singly or in multiples of two or more. About the exact nature of these bodies there is a controversy. Some authorities consider it as nutrient material of the cyst while others believe them as excess of chromatin thrown off during nuclear division. The chromatoid bodies occur in the early stages of the cysts but they disappear in the mature quadrinucleate cyst.

In young cysts glycogen is present in a diffused state and can be demonstrated in preparation with Lugol's iodine solution producing a brownish colour.

the cyst. In the 4-nucleate amoeba both the nuclei and cytoplasm divide and as a result 8 small amoebulae are produced (Fig. 9.24). These are called *trophozoites.* They are motile and penetrate the mucous membrane. Inside the tissues the trophozoites multiply and produce the characteristic lesions of amoebic dysentery.

The exact nature of the division of the nucleus is controversial but it is believed by many authors that it is probably a modified type of mitosis. The chromosome number of *Entamoeba histolytica* is stated to be six.

Transmission. Cysts of *Entamoeba* are transmitted from one individual to another in a variety of ways. The cysts are generally transmitted with food or drink.

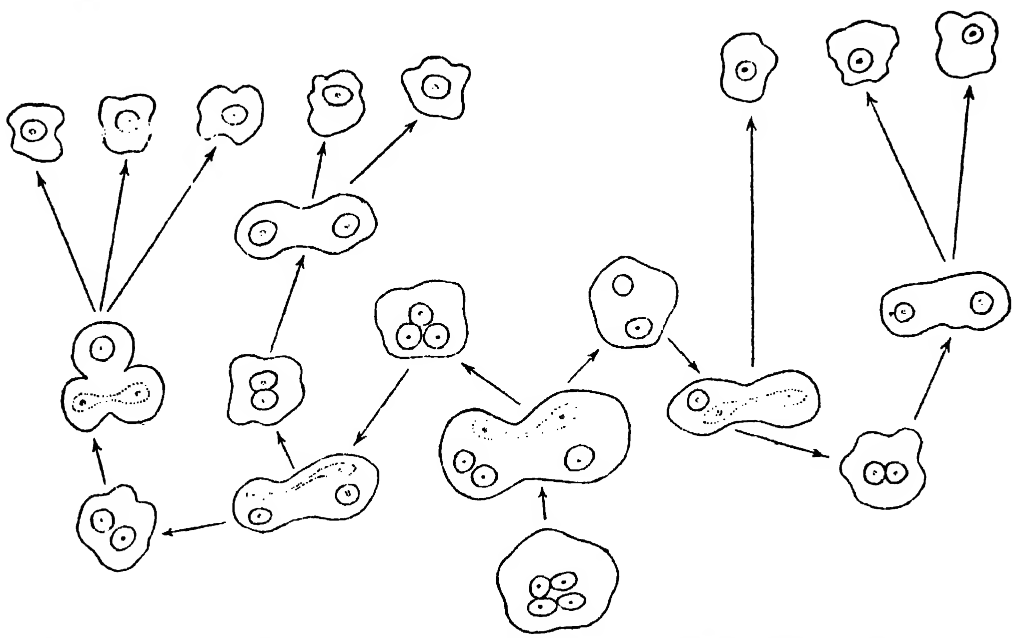


Fig. 9.24. Transformation of a quadrinucleate metacystic stage of *Entamoeba histolytica* to eight uninucleate trophozoites (after Kudo).

Life cycle. *Entamoeba histolytica* multiplies by binary fission in the trophozoite stage. They have the capacity to encyst. Prior to encystment, the parasite rounds up and eliminates food vacuole. A cyst wall develops and the nucleus divides first into 2 and then into 4 small nuclei. At this stage the cyst is infective to a new host. Through contaminated food or drink, the infective cysts pass into the lower portion of the small intestine of the new host. There the cyst wall becomes permeable by the action of the intestinal enzymes and 4-nucleate amoebae emerge out from

House flies and cockroaches may transmit cysts mechanically. Raw vegetable is also another source of infection. In many countries human faeces are used as fertilizer and thus roots and leaves of plants remain contaminated with viable cysts. Food handlers are also sometimes responsible for the spread of infection owing to imperfect personal sanitary measures.

Example of the Phylum Protozoa—*ELPHIDIUM* (*POLYSTOMELLA*)

Habit and Habitat. *Elphidium* is a

marine protozoa and is very common on the shore.

Structure. Body of the *Elphidium* is covered with a perforated calcareous shell or crest and it looks more or less like an ammonite shell in miniature. The shell consists of a number of chambers, arranged in a flat spiral and the surface of the shell is chiselled. Only the last whorl is visible from outside as each whorl is *equitant*, i.e. overlaps the previous whorl at the sides and hides it. The chambers are interconnected with each other through minute pores. The outer whorl opens to the outside by a row of large pores. The chambers are filled with protoplasm which is granular in nature. A thin layer of protoplasm covers the outerside of the shell. Pseudopodia are long, slender, often branched and come out from the pores of the shell as well as from the external layer of protoplasm (Fig. 9.25). The pseudopodia unite to form networks.

Elphidium is dimorphic and occurs in two forms, *Megalospheric* and *Microspheric*. The two forms are outwardly indistinguishable from each other but differ in internal organisation. In megalospheric form the central chamber or initial chamber is large (megalosphere) and bears a large single nucleus while in the microspheric form the central chamber is small (microsphere) and contains many small nuclei. The preponderance of megalospheric forms is about thirty times more than that of the microspheric forms.

Nutrition. *Elphidium* exhibits holozoic nutrition and feeds chiefly on diatoms, flagellates and unicellular algae. The pseudopodia are used in catching and entangling the food particles. The food entangled by the pseudopodia may be digested within the cytoplasm outside the test or it may be carried by the flowing cytoplasm to the chambers for digestion there.

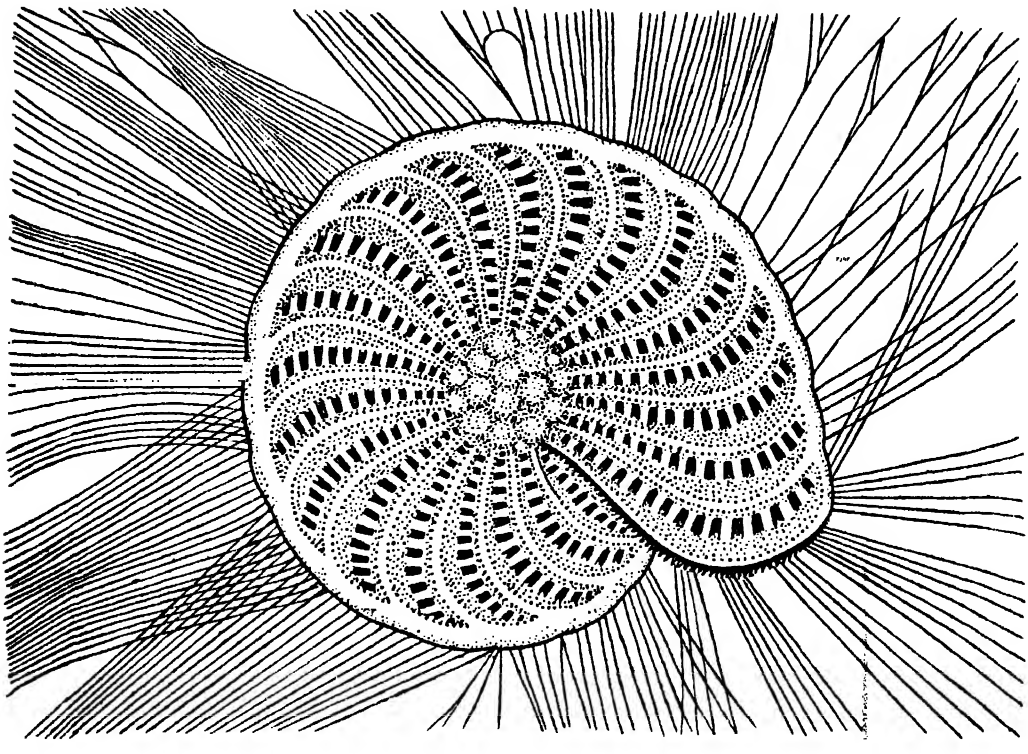


Fig. 9.25. *Elphidium strigilates* (*Polystomella*). Note the numerous thread-like pseudopodia (after Kudo).

Reproduction. *Elphidium* represents an alternation of generation in its life history (Fig. 9.26). The megalospheric forms alternate with the microspheric forms. The microspheric forms always develop from zygotes. The microspheric forms give rise to megalospheric forms which in turn

produce gametes. That means there is always an alternation of asexual and sexual generations.

The microspheric form divides asexually. The inner protoplasmic mass containing several nuclei creeps out of the shell and remains as a lump around it. A small amount of cytoplasm collects round each nucleus. As a result, a large number of small amoeboid cells are formed. Each of these cells develops into a *megalospheric form*.

During reproduction in megalospheric forms, the nucleus first breaks up into many small nuclei and the cytoplasm collects round each of these nuclei. The nuclei divide twice resulting into a large number of tiny cells. The cells develop flagella and come out of the shell and conjugate in pairs (Isogamy, i.e. fusion of similar gametes). The zygote thus formed develops into microspheric forms. The first division of the zygote is, however, reductional.

In some cases two megalospheric individuals are formed by direct fission of a megalospheric form.

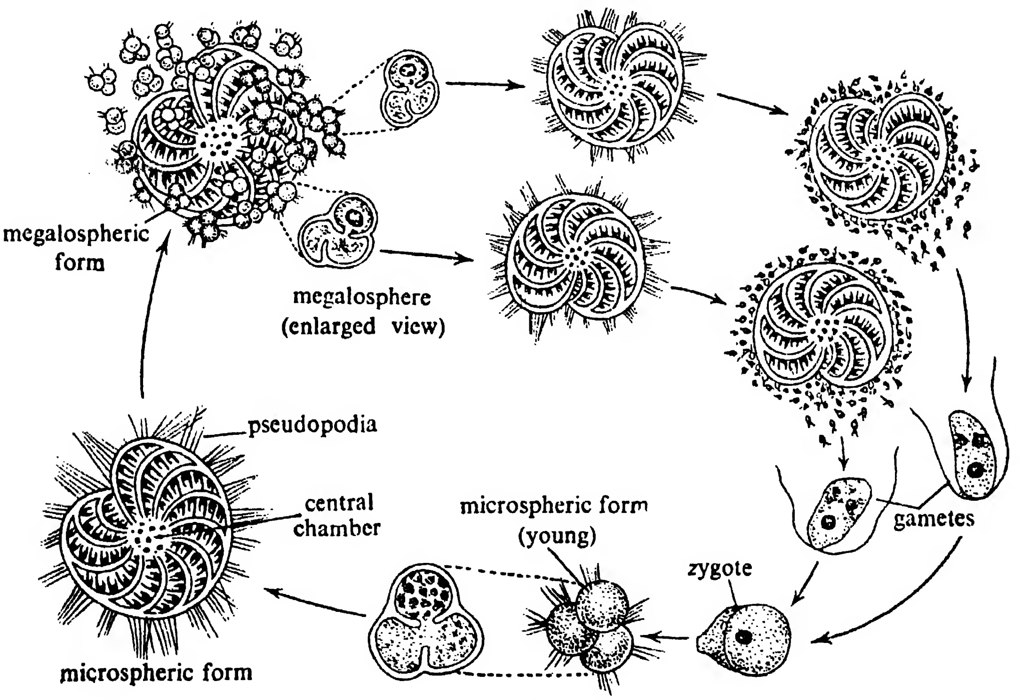


Fig. 9.26. Life cycle of *Elphidium crispa* (after Kudo).

Example of the Phylum Protozoa—*PLASMODIUM*

Members of the genus *Plasmodium* are collectively known as *Malarial parasites* because they cause a febrile disease called malaria. In the definitive host, i.e. man and other vertebrates, they invade the reticulo-endothelial system and in the intermediate host, i.e. female Anopheles, mosquito, they reside in the salivary glands.

Malaria as a chill and fever disease is known to mankind for a long time. The role of malaria in bringing about a turn in the history of Rome and Greece is advocated by many historians. The ravages of malaria entered these countries through the slaves imported from Africa. There exists a great malaria belt round the earth at the equator extending north and south to about fortieth parallels. The menace of malaria is a great hindrance towards the full utilisation of the resources of Africa and South America. Eradication of malaria is still a pioneer problem in public health.

Charles Laveran in 1880 discovered in

the red blood cells of a patient suffering from this chill and fever disease, the presence of some amoeba like organisms and he termed them *Plasmodium*. He injected the blood of a malaria patient into the blood stream of a healthy man and observed that fever develops in the injected man. Later on, many observers like Golgi and Celli confirmed the observations of Laveran. But its connection with the intermediate host and modes of transmission were experimentally worked out in Calcutta by Sir Ronald Ross in 1889. It is to the credit of Grassi (1890) who provided absolute scientific proof of the specific relationship between Anopheles mosquito and the human malarial parasites.

PLASMODIUM VIVAX. The life cycle of plasmodium may be divided in the following stages (Fig. 9.27).

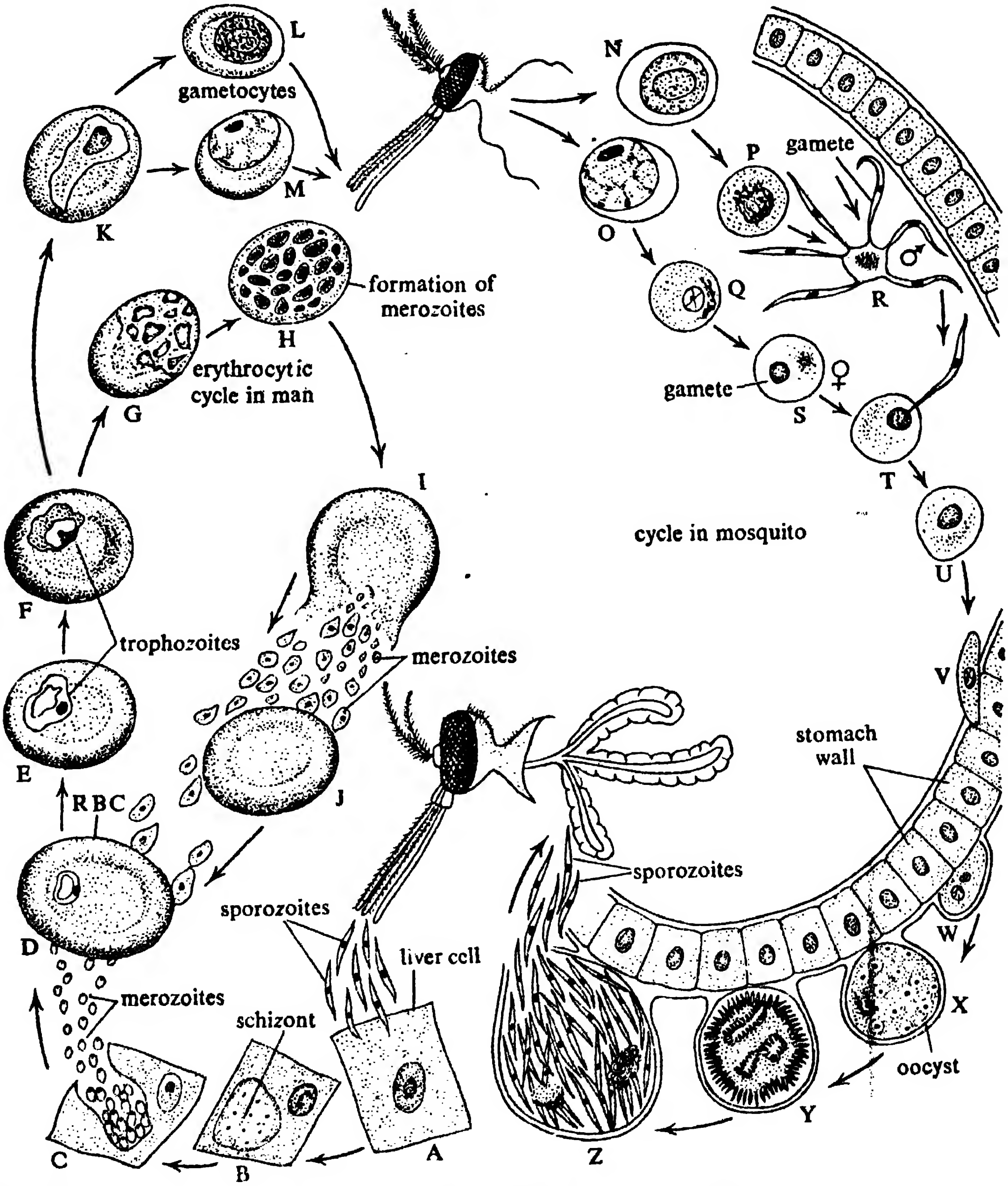


Fig. 9.27. Life cycle of a malarial parasite (*Plasmodium vivax*). A–C. Pre-erythrocytic cycle in liver cells. D–J. Erythrocytic cycle. K–S. Sexual cycle (begins in man and completes only within mosquito). T. Fertilisation. U. Zygote. V. Ookinete (piercing the stomach wall of mosquito). W–Z. Development of sporozoites.

I. Pre-erythrocytic cycle } in man.
II. Erythrocytic cycle } in man.
III. Exo-erythrocytic cycle } in man.
IV. Sexual cycle ... in female Anopheles mosquito.

I. **Pre-erythrocytic cycle.** The parasites are inoculated as sporozoites by the bite of the infected female Anopheles mosquito in the blood stream of man. The sporozoites are slender and spindle-shaped individuals measuring 15 micra in length and 1 micron in breadth. Within half an hour of their entry into the blood stream of man, the sporozoites take refuge in the liver paranchyma cells. The sporozoites remain within the parenchyma cells for about seven days. During this period, each sporozoite develops into a *Schizont*, which carries on multiple fission or schizogony. This phase of multiplication within the parenchyma cells is called *Pre-erythrocytic cycle*. Each schizont produces about 12000 merozoites. These pre-erythrocytic merozoites are set free by the rupture of the schizont. Newly produced merozoites go to liver sinusoids from where they invade fresh parenchyma cells or red blood corpuscles.

II. **Erythrocytic cycle.** Inside the red blood corpuscles the merozoites round up and soon develop into *trophozoites*. The young trophozoite grows at the expense of the red blood cells. It absorbs haemoglobin both by general body surface and pseudopodia. Soon after the entry of the merozoite into the corpuscle, a non-contractile vacuole develops in its body and the nucleus is pushed to one side. The shape of the trophozoites resembles a ring at this stage and is called *signet-ring stage*. The vacuole disappears with further growth. A full-grown trophozoite assumes a round shape and occupies the whole of the RBC. They are found to contain yellowish brown haemoglobin pigment. In about 48 hours a trophozoite becomes full-grown and it multiplies by schizogony. When the schizont bursts a number of erythrocytic merozoites (approx. 16) are set free. These merozoites enter fresh red blood corpuscles and the cycle is repeated (Fig. 9.28).

III. **Exo-erythrocytic cycle.** The erythrocytic merozoites entering the fresh RBC carry on exo-erythrocytic schizogony and as a result each schizont produces about 1,000 exo-erythrocytic merozoites. These merozoites invade fresh RBC. In the RBC the merozoites carry on erythrocytic cycle. This exo-erythrocytic cycle

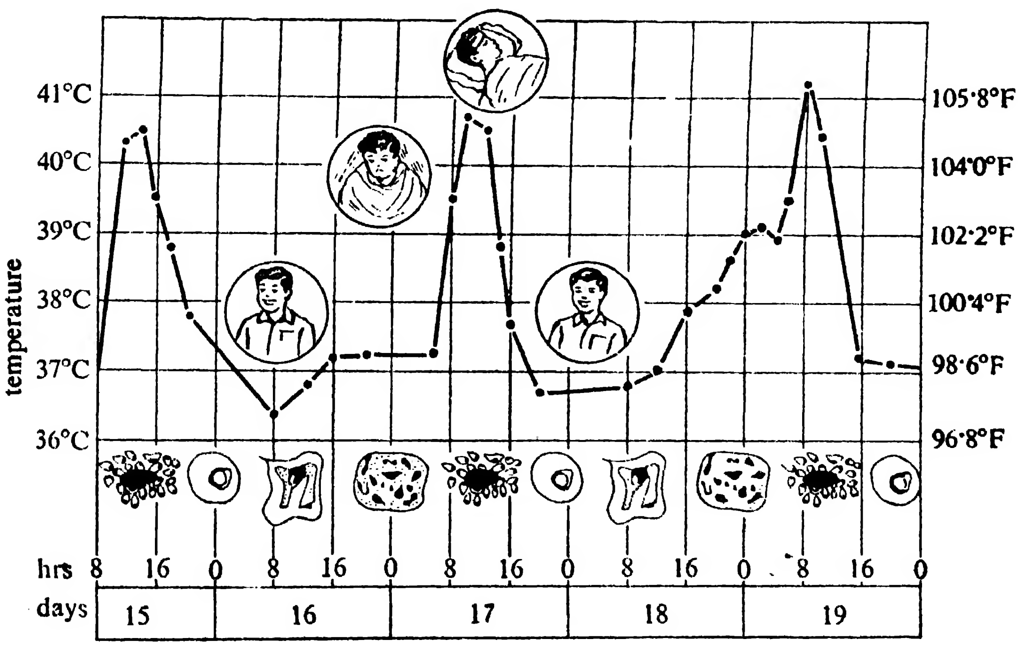


Fig. 9.28. Temperature cyle in malaria caused by *Plasmodium vivax* (after Sherman). Note the changes in the erythrocytic trophozoites corresponding to the changes in body temperature.

was recorded in monkey, where malaria is caused by *Plasmodium cynomolgi*. As *P. cynomolgi* is very much similar to *P. vivax*, it is assumed that an identical exo-erythrocytic cycle also occurs in man.

IV. **Sexual cycle.** Some of the merozoites behave differently from those which repeat schizogony in RBC. At the end of their trophic phase they do not divide but come out into the plasma by rupturing the red blood cells. These individuals are designated as *gamonts* or gametocytes. There are two forms of full-grown gametocytes—the female or *macrogametocyte* and male or *microgametocyte*. The macrogametocytes are larger in size compared to the microgametocytes, take deep stain and contain many pigment granules. The nucleus is round and is situated marginally. The microgametocyte takes faint stain and the nucleus is centrally located. Further development of the gamonts does not take place within human body. When a female Anopheles mosquito bites an infected man, the ingested blood fills her stomach. All other forms excepting the gametocytes die in the stomach. In the stomach the macrogametocyte becomes spherical and transforms into the *macrogamete* ready to be fertilised. The changes in the microgametocyte are more marked. Five minutes after ingestion it becomes spherical and five to six filamentous motile appendages emerge. This process is called *exflagellation*. These appendages are not true flagella but are male individuals or *microgametes*. The microgametes become free and start moving towards macrogametes and ultimately one microgamete fertilises one macrogamete. Fertilisation has been seen to occur ten minutes after the ingestion of blood.

The fertilised macrogamete or *zygote* becomes elongated in shape and motile in habit after 24 hours. In this new state it is called the *ookinete* or *vermicule*. The ookinete forces its way through the internal lining of the stomach of the mosquito and comes to rest in the subepithelial tissue. The ookinete in this new site becomes round and encased in a covering or cyst derived partly from stomach tissue and partly from its own secretion. The ookinete is now termed the *oocyst* or *sporont*. Howard's [Howard, L. (1960) studies on the mechanism of infection of mosquitoes by malaria parasites, D.P.H. Thesis, John Hopkins University.] is of the opinion that only the zygotes that remain in the periphery of the blood meal of the mosquito become lodged between the cells of the mosquito stomach wall to develop as *oocysts*. Those zygotes who fail to get shelter in the stomach wall of the mosquito develop into *ookinete*. The ookinete is voided with the faeces and as such they are nothing but dying parasites. Thus according to Howard "The long-held assumption that ookinete is motile invasive zygote is an example of a concept based on observations which were never made". Oocyst formation becomes complete after 48 hours of ingestion. The oocyst increases in size and measures 6–7 micra. The oocysts bulge on the outer wall of the stomach towards the haemocoele and render the stomach wall blistered. In severe infections as many as 5,000 cysts may be seen. After about seven days a number of lobes are formed in the oocyst and *sporogony* occurs. During which the zygote nucleus divides into a number of nuclei. The first division of the zygote is believed to be meiotic in nature. Portions of protoplasm of the oocyst collect round each nucleus and thousands of daughter individuals called sporozoites are formed. The muscular wall enveloping the oocyst bursts and cluster of sporozoites are liberated in the haemocoele. The sporozoites find their way into the salivary glands of the mosquito.

They are introduced into human body when the mosquito injects saliva during a bite.

OTHER MALARIAL PARASITES

The members of the genus *Plasmodium* are recognised as the causative agent of malaria in man. They are: *P. vivax*, *P. malariae*, *P. falciparum* and *P. ovale*. They cause Benign tertian, Quartan, Malignant tertian and Ovale tertian fever respectively. In Benign tertian outbreak of fever occurs every other day, in quartan fever the outbreak sets in every third day while malignant malaria is irregular occurring almost daily and is often fatal. Chief differences between the four species are tabulated in Table 5—Protozoa.

TABLE 5—PROTOZOA

Chief differences between the four malarial parasites

	P. vivax	*P. malariae*	*P. ovale*	*P. falciparum*
1. Period of incubation	11–14 days	18–21 days	9 days	9–12 days
2. Period of Schizogony	48 hours	72 hours	48 hours	24–48 hours
3. Number of merozoites	12–24	6–12	6–12	18–24
4. Arrangement of merozoites	In two rings	Rossette like	Irregular	Irregular
5. Shape of gametocyte	Round	Round	Oval	Crescent
6. Pigments	Yellowish brown	Dark brown	Dark yellowish brown	Dark brown

EXAMPLE OF THE PHYLUM PROTOZOA—*MONOCYSTIS*

Habit and Habitat. *Monocystis* lives as an endoparasite in the seminal vesicle of earthworms. The various phases of its life cycle become complete within the seminal vesicle.

Structure. The trophozoites are fusiform in shape (Fig. 9.29). The outer covering of the body is called the *pellicle*

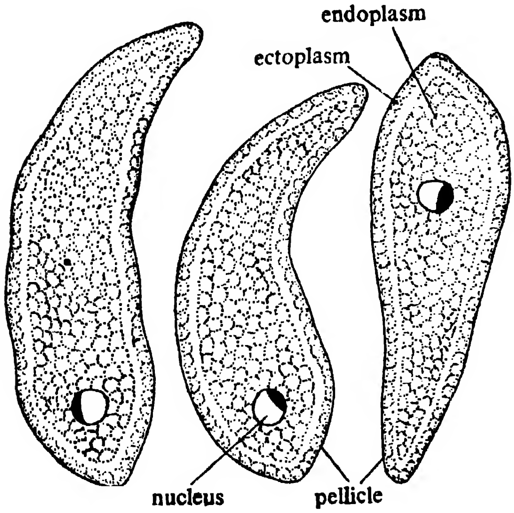


Fig. 9.29. Trophozoites of *Monocystis*.

which is smooth and thick. Within the pellicle the cytoplasm is differentiated into an outer non-granular *cortex* or ectoplasm and an inner granular *medulla* or endoplasm. The endoplasm is rich in granules of glycogen-like carbohydrate, lipid droplets and other inclusions. Just below the pellicle, there are fibre-like contractile structures called *myonemes*. The nucleus is placed centrally. Food vacuoles and contractile vacuoles are absent.

Locomotion. The wriggling movement of the otherwise sluggish monocystis is brought about by the contraction and expansion of the myonemes which are arranged in lines below the pellicle. The movement is slow but strong. The type of locomotion encountered in Monocystis is called *gregarine movement*.

Nutrition. As an endoparasite the trophozoites of *Monocystis* live at the expense of the protoplasm of the sperm morula which remains stored in the seminal vesicle.

The torphozoites secrete digestive enzymes which act on the surrounding sperm cells of the earthworm and render them assimilable. The nutrient substances thus produced are absorbed through the whole cell surface or pellicle. Thus digestion in *Monocystis* is *extracellular* and the mode of nutrition is *saprozoic*.

Respiration. *Monocystis* respires by the process of diffusion. As the parasite lives within the body of the earthworm the chance of getting free oxygen is very remote. It is presumed that *Monocystis* gets its oxygen supply either by the process of fermentation of carbohydrate occurring in the body of the host or from the seminal vesicle, which gets its quota of oxygen from the blood of earthworm. The carbon dioxide produced diffuses out from the body and is finally eliminated through the blood of the host.

Excretion. The metabolic wastes diffuse out of the body of *Monocystis* into the host tissue and are eliminated by the excretory organs of the host.

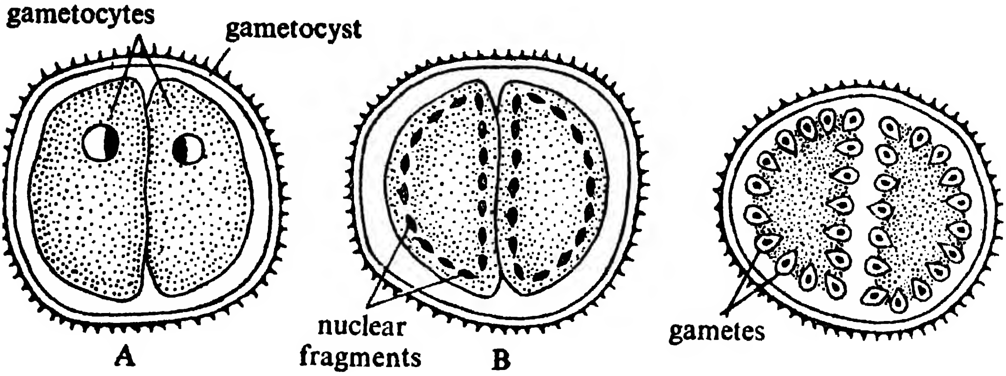


Fig. 9.30. Stages of life history in *Monocystis*.
A. Gametocytes within the gametocyst. B. & C. Formation of gametes by multiple fissions.

Reproduction. *Monocystis* reproduces *sexually* and the process is always followed by asexual reproduction. In fact, the two processes are interdependent.

Sexual reproduction. During sexual reproduction two mature trophozoites called *gametocytes* or *gamonts* come close together and secrete around themselves a double-walled cyst. The cyst is called *gametocyst* or *gamontocysts* (Fig. 9.30A). The nucleus of each gametocyte divides a number of times and produces large number of daughter nuclei (Fig. 9.30B). The final nuclear division in case of *Monocystis rostrata* is *meiotic* or reductional in nature. The nuclei thus formed become arranged along the periphery of each gametocyte. Each nucleus collects a little mass of cytoplasm round it and becomes a *gamete* (Fig. 9.30C). The gametes produced in each gametocyte are equal in number and similar in shape. Finally, the line of demarcation between the gametocytes breaks and the gamete of one gametocyte fuses with the gamete of the other gametocyte. The fusion results in the formation of a zygote (Fig. 9.31D). The zygote formed inside a gametocyst is equal in number to the gametes present in each gametocyte.

Asexual reproduction. The zygote which is called *sporont* or *sporoblast* secretes a hard covering round it. The covering is called *zygocyst*. The cysted zygote is now called the *pseudonavicella* for its boat-shaped appearance and resemblance to the genus

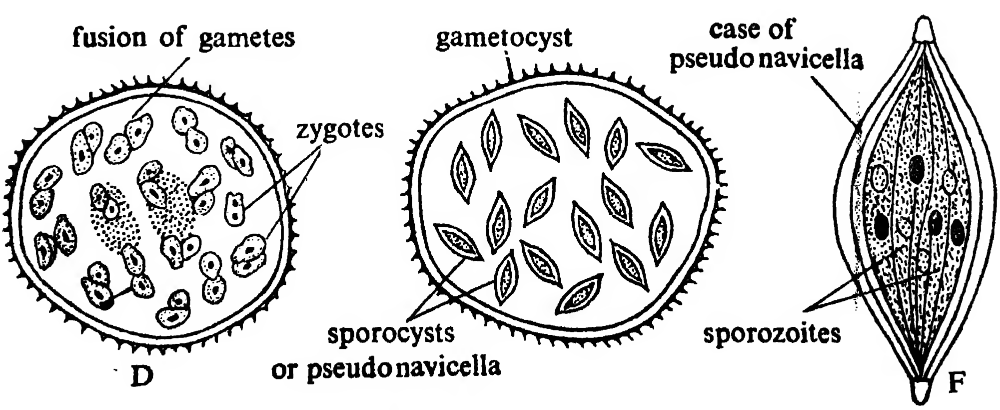


Fig. 9.31. Stages of life history in *Monocystis* (contd.)
D. Formation of zygotes by the fusion of two individual gametes. E. Gametocyst enclosing pseudonavicellae. F. Sporozoites within a pseudonavicella.

Navicella (Fig. 9.31E). Within the zygocysts the zygote undergoes three successive divisions two of which are meiotic and one mitotic and as a result eight fusiform sporozoites are formed (Fig. 9.31F). On reaching the *seminal vesicle* of another earthworm the cyst wall breaks and the sporozoites are liberated (Fig. 9.32G). The sporozoites infect a sperm mother cell and leads an intracellular life (Fig. 9.32H). After some time it comes out of the cell in the seminal vesicle. It then resembles a trophozoite in appearance, but numerous tails of the earthworm sperms project from its surface (Fig. 9.32I). Soon it sheds off those tails

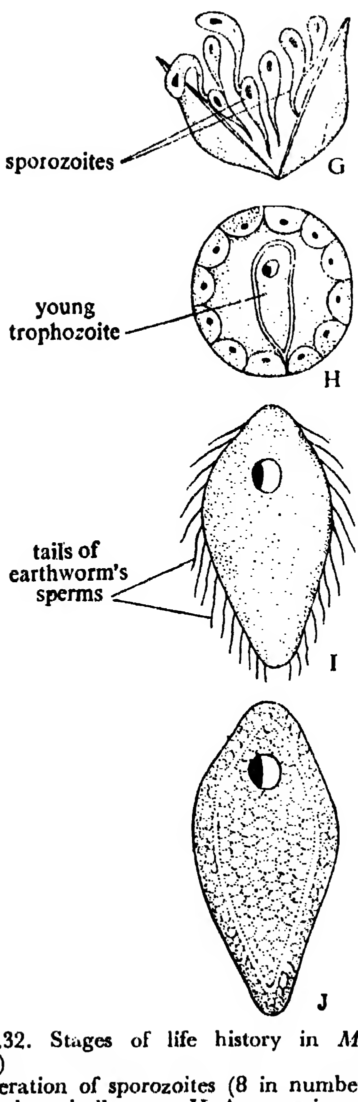


Fig. 9.32. Stages of life history in *Monocystis* (contd.)
G. Liberation of sporozoites (8 in number) from the pseudonavicellar case. H. A young intracellular trophozoite. I. A young trophozoite. J. An adult trophozoite.

and becomes a trophozoite (Fig. 9.32J) and thus the life cycle becomes completed (Fig. 9.33). These trophozoites are *haploid* individuals and the gametes are haploid. This zygote is the only *diploid* stage in the life cycle.

Transmission. The transmission of the sporocysts from one earthworm to another is a matter of speculation and the following possibilities are advocated:

(*i*) When an earthworm, infested with the parasites, dies the sporocysts are liberated in the soil.

(*ii*) When an infested earthworm is eaten up by a bird, the resistant sporocysts are not digested and come out to the soil along with the faeces of the birds. When the soil containing the sporocysts is swallowed by an earthworm the cyst wall gets dissolved in the intestine and sporozoites make their way into the seminal vesicle.

(*iii*) The third possibility is that the sporocysts are transferred from one host to another during copulation or exchange of sperms from the seminal vesicle of one earthworm to another.

Example of the Phylum Protozoa—*PARAMOECIUM*

Habit and Habitat. *Paramoecium*, popularly known as the slipper animalcule for its peculiar shape, is found in abundance in stagnant ponds and organic infusions. They can be seen with naked eyes as white specks moving about very rapidly in the medium. *Paramoecium* is cultured in the laboratory in hay infusions. The type described here is known as *Paramoecium caudatum*.

Structure. It measures about 0·25 mm in length. Body is somewhat cylindrical but flattened (Fig. 9.34). One end of the body is slender and blunt and remains foremost during locomotion. Obviously this is the *anterior* end. The other end or the *posterior* end is thick and pointed. The surface of the body which is with a groove and always faces the substratum is called the *oral* or *ventral* surface while the opposite is *aboral* or *dorsal* surface.

Body is covered with a distinct, tough and flexible *Pellicle*. The pellicle is sculptured into hexagonal depressions (Fig.

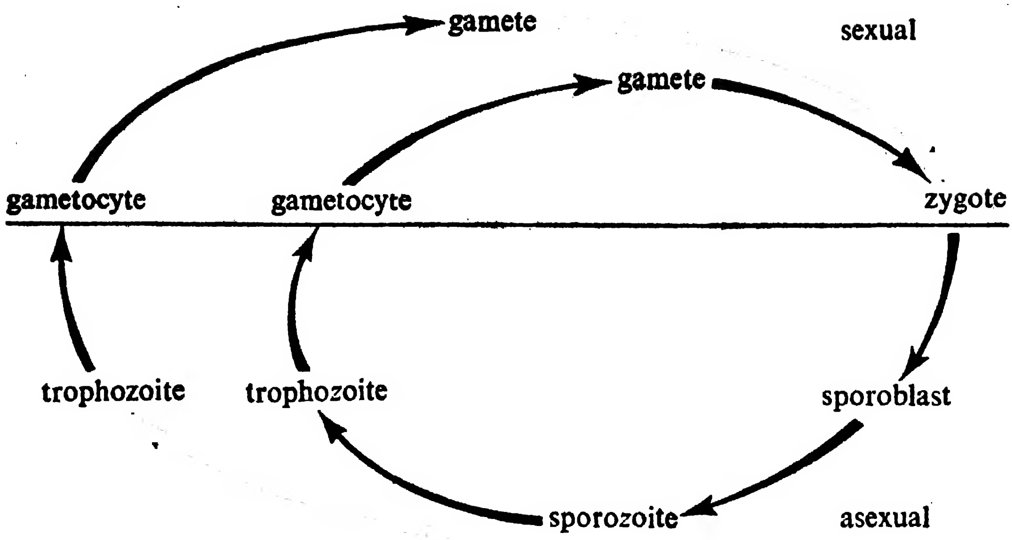


Fig. 9.33. Life cycle of *Monocystis*.

9.35A). The depressions are provided with holes at the centre through which the cilia project. Each cilium originates from a *basal granule* situated in the cortex. The basal granules are inter-connected with each other through fibres called *neuroneme*. Each cilium is made up of an axial filament, the *axoneme*, surrounded by a protoplasmic sheath. The section of a cilium under electron microscope shows the presence of nine '8'-shaped circularly arranged filament and a similar single cylindrical filament at the centre (*see* Fig. 9.51). The cilia are arranged in longitudinal rows. Beneath the pellicle the protoplasm is differentiated into *cortex* and *medulla*. The cortex or ectoplasm is clear, non-granular, less extensive and contains many spindle-shaped bodies called *trichocysts*. Trichocysts are about 1/100 mm in size and are arranged as rows of sacs having their closed sides towards the inner layer. The trichocysts are filled with homogeneous, refractive and semi-fluid substances. On being stimulated the content comes out through small openings on the ridges of the pellicle. When the stimulations are very strong the trichocysts themselves are expelled out of the body as long threads (Fig. 9.35B). In the anterior side of the body the cilia are arranged in a spirally twisted course. The cilia lining the *gullet* are larger in size. A special ciliary structure called *penniculus* is formed by the fusion of four rows of cilia. Two such penniculi are seen in the gullet region (Fig. 9.35C). The medulla or endoplasm is granular and bears at the centre the nuclear apparatus consisting of a large kidney-shaped *macronucleus* and a small round *micronucleus* is placed in the concavity of the macronucleus. The macronucleus is concerned with ordinary life processes while the micronucleus looks after the reproductive part. There are two star-shaped *contractile vacuoles*, situated one on either end of the body. Each vacuole consists of a large *central vesicle* into which open a number of *radiating canals*. Food vacuoles are many and contain inside them food particles at different stages of digestion.

On the ventral side of the body is situated the *oral groove* (Fig. 9.35D), which runs obliquely backward and opens into a funnel-shaped depression called the *gullet* or *cytopharynx* through an aperture called *cytostome*. Undigested food particles are eliminated through a definite *anal spot* (or cytopyge) situated posterior to the mouth.

Locomotion. *Paramoecium* exhibits two types of movement—(*a*) Creeping and (*b*) Swimming.

Creeping. During creeping movement the animal uses its cilia of the oral surface as miniature legs and simply glides over the obstacles. As the pellicle is thin

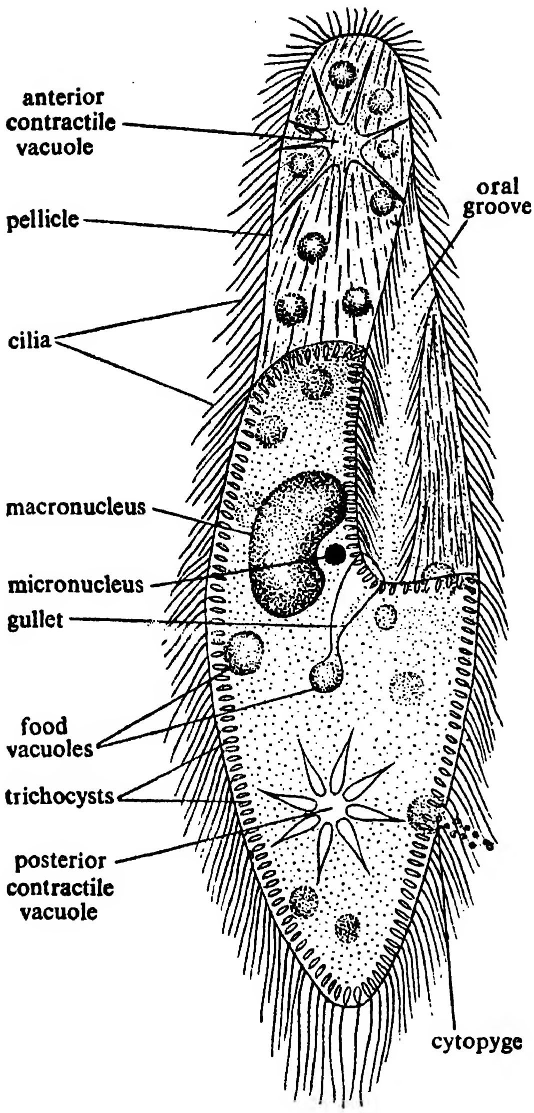


Fig. 9.34. *Paramoecium caudatum.* The pellicle is partly removed to show the internal organisation.

and elastic the animal can easily bend and squeeze through gaps narrower than its own body diameter.

Swimming. The animal can swim forwards and backwards. Individual cilium of a progressing animal bends throughout its length and strikes the water and thus the animal moves in a direction opposite to the effective stroke and water moves in the direction of the stroke. That means, if the animal intends to move forward it holds the cilia inclined backwards and then makes rapid, concerted and repeated strokes. The animal swims in an elongated spiral path and the individual body rotates upon its own longitudinal axis. This is possible due to the longitudinal arrangement of cilia on the body surface (Fig. 9.36).

The organised movement of cilia is controlled by the neuronema or the neuromotor system in the body.

Nutrition. *Paramoecium* is a typically *holozoic* animal. It feeds on other protozoa, bacteria and minute particles of animal and vegetable matter suspended in the medium. The cilia lining the oral groove perform a great role in capturing food particles. During ingestion these cilia make a co-ordinated beating and as a result a continuous current of water containing food particles passes down the gullet. The food particles are believed to be paralysed by the toxic product of the trichocysts. The food particles are collected at the bottom of the gullet and are worked into balls by the cilia. These foodballs or bolus, along with some water, pass through the cytostome to form *food vacuoles* in the endoplasm. The formation of the food vacuole is a continuous process and as soon as one food vacuole detaches from the gullet another one starts forming. The food vacuoles move in a definite course of *circulation* or *cyclosis* inside the endoplasm by its streaming movement. The food vacuoles first travel to the posterior end then take a turn and travel anteriorly. They reach the anterior border of endoplasm and travel back and come to the middle of the body to complete the circulation. The colour of the contents gradually changes from green to yellow. The food is digested during the sojourn and the mode of digestion is similar to that of *Amoeba*. The animals cannot digest fat. Undigested residue of food is thrown out through the *cytopyge* or cell anus situated on the ventero-posterior surface. The cell anus is only visible during the act of excrement.

Respiration. Oxygen, dissolved in water, enters the body through the surface by *diffusion* and carbon dioxide comes out in the same manner.

Osmoregulation and Excretion. The two contractile vacuoles are effective osmoregulatory organelles. Each contractile vacuole is provided with 6–11 *radiating*

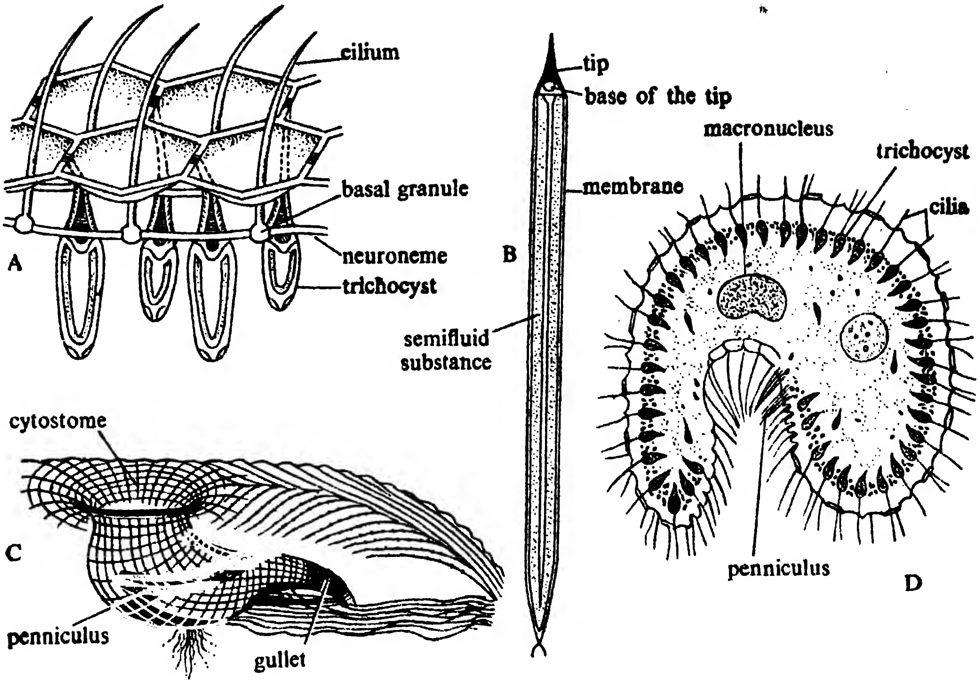


Fig. 9.35. Various structures of *Paramoecium* (modified from various sources).
A. A highly magnified view of the pellicle. B. A discharged trichocyst. C. The fibrillar system around cytopharynx. D. Transverse section through the cytopharynx.

or *inhalent canals* which go deep into the endoplasm and collect excess of water. The inhalent canals pour their contents into the central vacuole which after attaining maximum size bursts to liberate the contents outside the body. Concurrent contraction of the two central vacuoles does not take place. The time lapse between the contraction of two vacuoles is usually 10–12 seconds.

Some workers consider the radiating canals as *formative vacuoles*. They have put forward the view that after the contraction of the central vacuole, the formative vacuoles come together and fuse at their inner ends to form a new central vacuole round which new formative canals gradually develop.

Reproduction. *Paramoecium* reproduces both by asexual and sexual methods.

Asexual reproduction. It takes place by *transverse binary fission* and is the common mode of reproduction (Fig. 9.37). During binary fission the micronucleus divides *eumitotically*, i.e. by passing through all the stages of mitosis and the macronucleus divides *amitotically*. The products of these divisions are two macronuclei and two micronuclei. One macronucleus and one micronucleus go to the anterior part while the other pair go to the posterior part. Finally, a constriction appears in the middle of the body of the animal and two daughter paramoecia are formed. The oral groove is usually inherited by the daughter at the anterior end. However, in both of them the division is always followed by regeneration of lost parts. The whole process of division normally takes about 2 hours. The rate of division is dependent on availability of food and on temperature. Two to three divisions are not uncommon in 24 hours time.

Sexual reproduction. After practising binary fission for a considerable number of generations, the paramoecia make a nuclear reorganisation by *conjugation* or *mating* (Fig. 9.38).

During conjugation two individuals called *conjugants* or *gametocytes* come close together and pair by the ventral surface. The interlocking between them is made stronger by the *gullets* which degenerate to form a *protoplasmic bridge* between them.

The paired conjugants are, however, capable of movement. Soon a series of changes

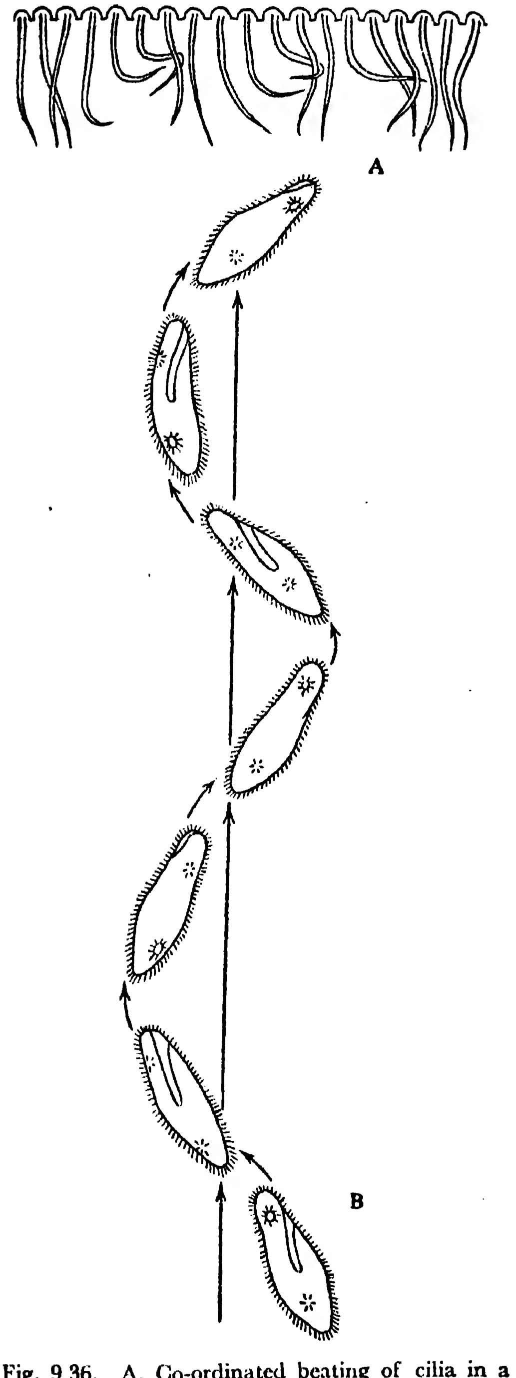


Fig. 9.36. A. Co-ordinated beating of cilia in a part of the body of *Paramoecium*. B. Course of progress of *Paramoecium* durihg locomotion. Note that the body rotates on its own axis during the forward movement.

occur in the nuclei of both the conjugants which are to some extent comparable to *gametogenesis* of higher animals. These nuclear changes are:

(I) The macronucleus undergoes gradual disintegration and ultimately disappears.

(II) The micronucleus undergoes two successive divisions forming four micronuclei in each of the conjugants. One of the divisions is probably meiotic in nature.

(III) Three of these four micronuclei in each conjugant degenerate and the remaining one undergoes an unequal division to form two gamete nuclei. One of the gamete nuclei is large and is called the *stationary nucleus* while the small one is called the *migratory nucleus*.

(IV) The migratory nucleus of one conjugant goes to the stationary nucleus of the other and *vice versa* through the protoplasmic bridge.

(V) The migratory nucleus of one conjugant ultimately unites with the stationary nucleus of the other and forms the *zygote nucleus*.

(VI) The conjugants with the zygote nucleus now separate and are called *exconjugants*.

(VII) In each exconjugant the zygote nucleus undergoes three successive divisions forming eight nuclei.

(VIII) Of these eight nuclei four become macronuclei and four become micronuclei. Later on three of the four micronuclei degenerate leaving behind one active micronucleus.

(IX) The micronucleus divides and cytoplasmic division follows resulting into two paramoecia from each exconjugant and each of the two paramoecia is provided with two macronuclei and one micronucleus.

(X) The micronucleus divides again, followed by the cytoplasmic division, resulting four paramoecia each with one micro- and one macronucleus.

(XI) Thus from each exconjugant four paramoecia are formed.

Mating type. In *Paramoecium aurelia*, two kinds of individuals, having considerable sexual differentiation, are present. The members of these different classes conjugate with each other but the members of same class do not. The members of the class which do not conjugate amongst

themselves are progeny of one of the two individuals formed by the first divisions of exconjugants and incidentally are all equipped with same and identical constitution. The classes which conjugate have been termed as *mating types*. Presence of such mating types in *Paramoecium caudatum* has also been observed.

Autogamy. This is a sort of regularly recurring nuclear reorganisation in solitary *Paramoecium aurelia*. Some of these nuclear changes are almost identical to the changes which occur during conjugation. The chief difference is that fusion occurs between two nuclei which originate in a single paramoecium. The phenomenon has been termed *autogamy* (Fig. 9.39). In *Paramoecium aurelia* there are two micronuclei and one macronucleus. During the process the two micronuclei divide twice forming eight micronuclei. Seven of these micronuclei degenerate and the remaining one divides for the third time producing two *functional nuclei*. The functional nuclei travel to the *paraoral cone* and fuse to form the *synkaryon*. Paraoral cone forms as a projection at the level of oral groove. The synkaryon divides twice to form four nuclei. Two of these four nuclei now metamorphose into macronuclei. The old macronucleus in the mean time undergoes fragmentation and disintegration. By another division of the cell and micronucleus two paramoecia are formed having normal nuclear apparatus.

In conjugation, possibilities are there for *variation* whereas autogamy gives *pure lines*. It has been observed that autogamy occurs after the emergence of a *depression* stage in the individual. This depression stage is always indicated by an increase of volume and definite sluggishness on the part of the animal.

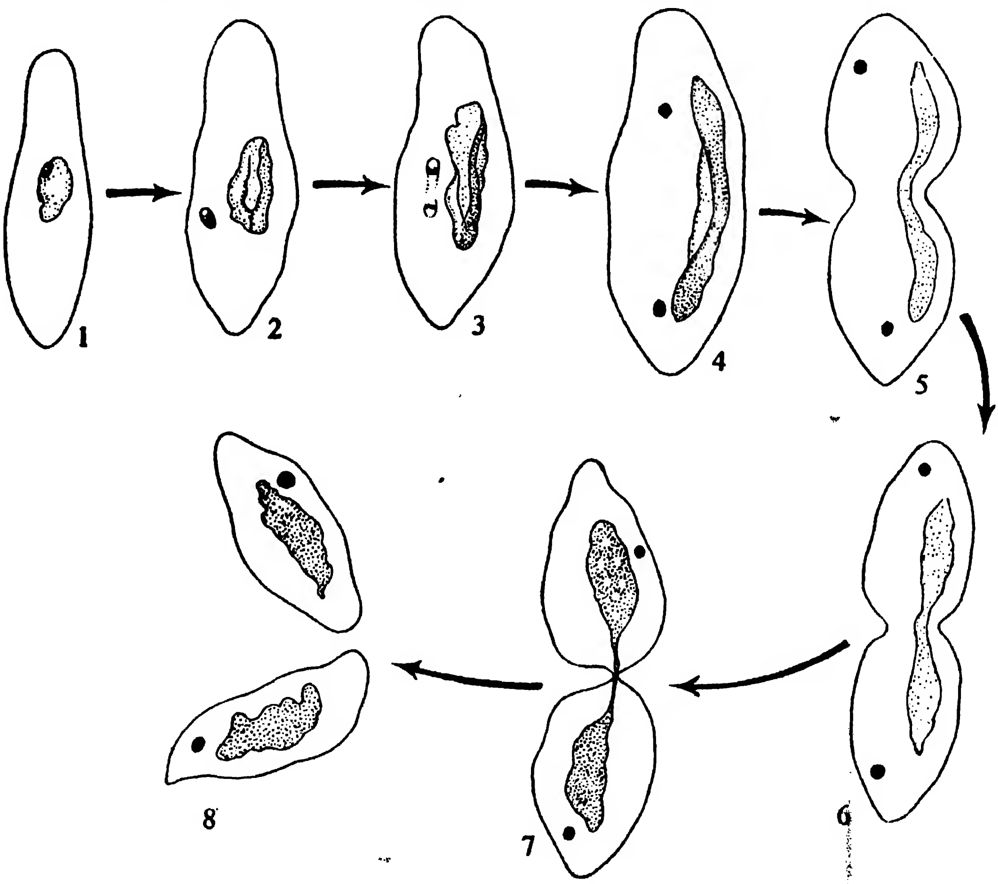


Fig. 9.37. Binary fission (transverse) in *Paramoecium*. Entire process is completed within two hours (after Kudo).

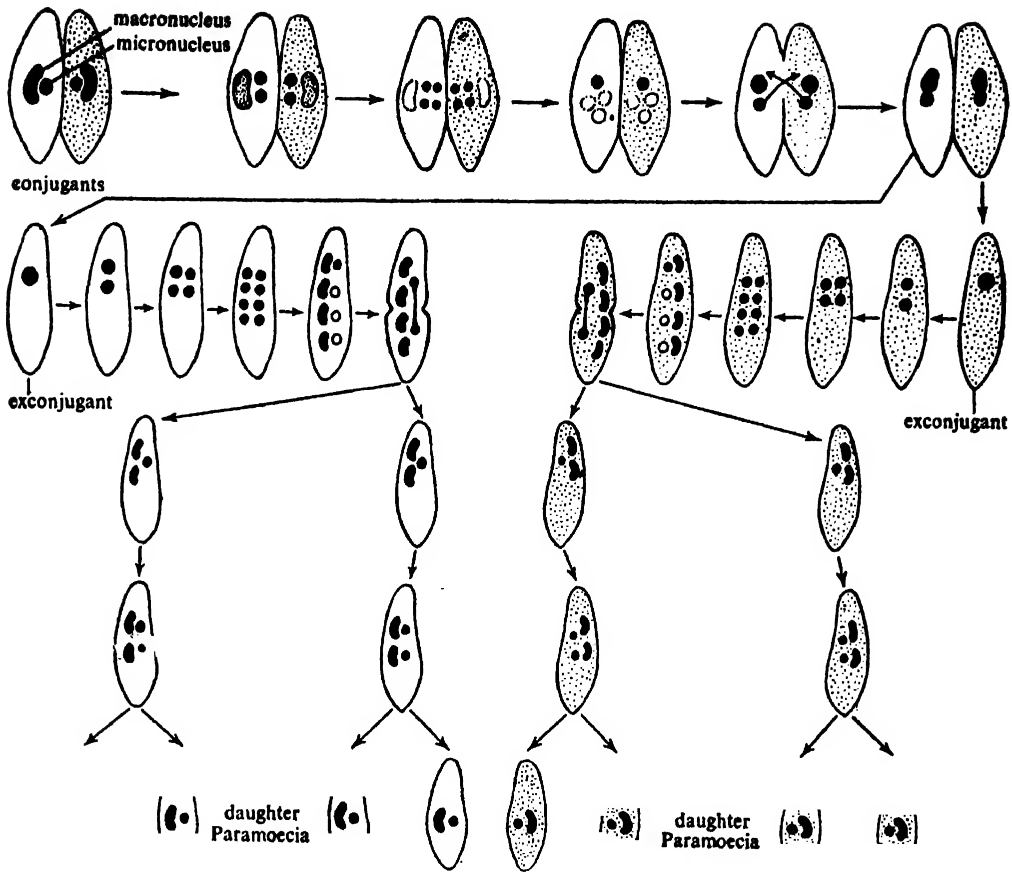


Fig. 9.38. Stages of conjugation in *Paramoecium caudatum* (diagrammatic). Note that two individuals (shown in different shades) come together, exchange their nuclear material and then separate. Each individual ultimately produces four daughter paramoecia.

Irritability

(I) **Response to mechanical stimuli.** In *Paramoecium* the anterior end is more sensitive than the posterior end and offers positive or negative responses.

(II) **Response to gravity.** *Paramoecium* exhibits negative reaction to gravity and in a culture jar resides just below the surface of the medium.

(III) **Response to chemical stimuli.** *Paramoecium* shows positive reaction to weak chemical solutions of acids and negative reaction above certain concentration. Paramoecium can thrive in a drop of medium containing 0·02 per cent acetic acid but if the concentration of the acid is increased the animal moves away and takes refuge in the periphery where the acid is diluted by the surrounding water.

(IV) **Response to electrical stimuli.** *Paramoecium* moves to the anode when electric current is passed through the medium where it lives.

Example of the Phylum Protozoa—*VORTICELLA*

Habit and Habitat. Vorticella is popularly known as bell animalcule. It grows on the stems of fresh water or marine plants and appears as white fringes to the unaided eyes. Vorticella is solitary but its related form *Carchesium* are colonial.

Structure. Structures of vorticella suggest an inverted solid bell having a long handle (Fig. 9.40A). The base of the handle or stalk remains fixed to the object

of anchorage and is capable of contraction. The handle is formed by a prolongation of the body, encased in cuticle and it contracts by means of *myoneme*. The bell is provided with a thick margin. The depressed disc-like structure within the margin is called the *peristome*. The depression bears an opening which leads into a distinct passage called the *vestibule* (Fig. 9.40B). A permanent *anus* or *cytopyge* is situated close to the vestibule. Cilia are restricted to the mouth region and are arranged in inner and outer concentric rows and form an undulating

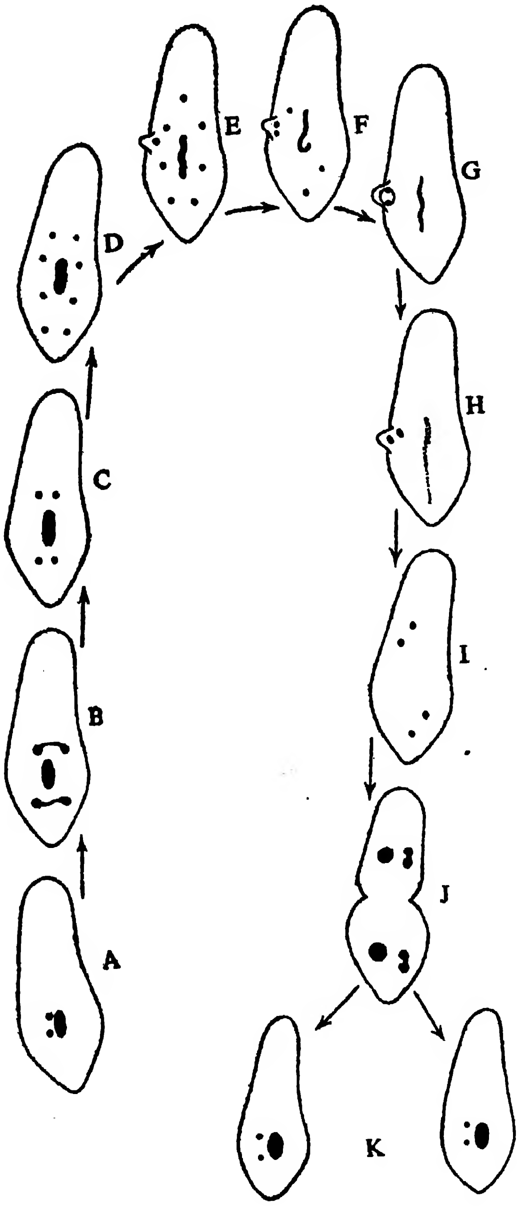


Fig. 9.39. Autogamy in *Paramoecium aurelia*. A–E. Macronucleus gradually degenerates and the two micronuclei divide repeatedly. F. Two daughter micronuclei enter within a conical projection. G. These two unite while the others degenerate. H, I. The fused nucleus divides twice to produce four nuclei. J. Two of the nuclei develop into macronuclei and the remaining two divide again. The individual divides into two, each gets one macronucleus and two micronuclei.

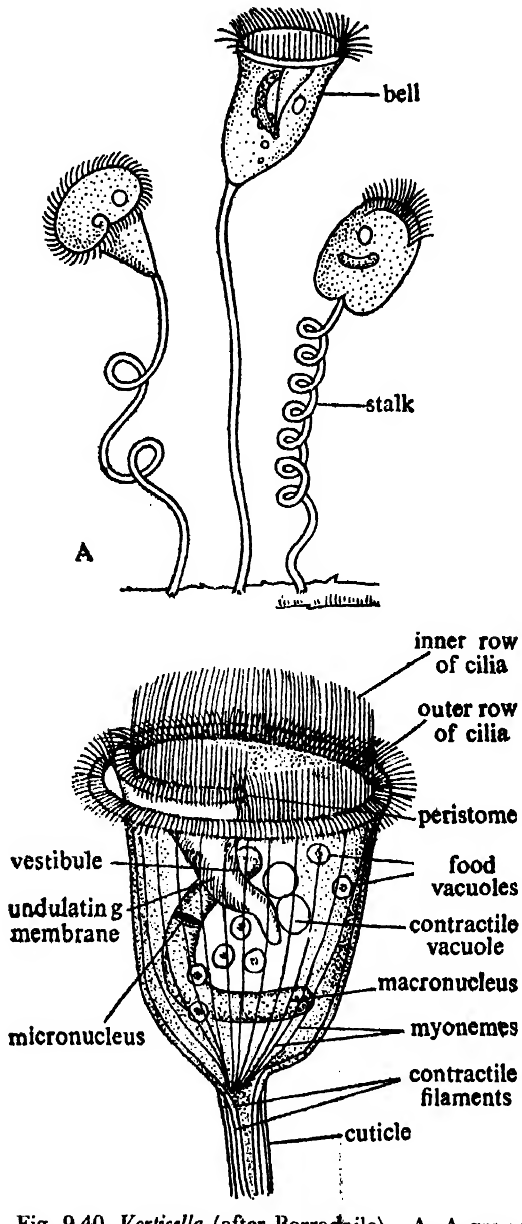


Fig. 9.40. *Vorticella* (after Borradaile). A. A group of individuals at various states of contraction of their stalks. B. Magnified view of the upper end of an individual.

membrane in the vestibule. The cilia have the usual structural pattern. The *macronucleus* is large and horseshoe-shaped while the *micronucleus* is small and round. A single *contractile vacuole* is present, though *food-vacuoles* are many.

Reproduction. Vorticella reproduces both asexually and sexually (Fig. 9.41).

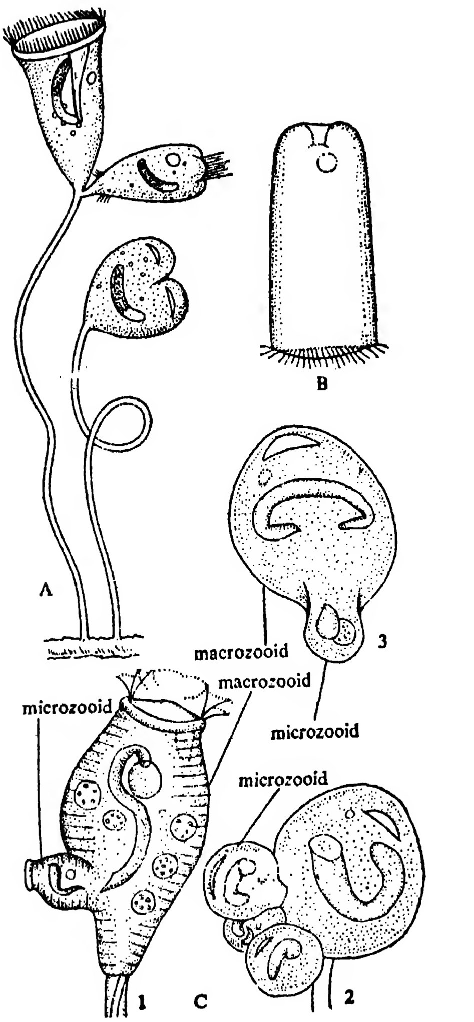


Fig. 9.41. Different modes of reproduction *Vorticella* (after Borradaile).
A. Longitudinal fission (right shows the beginning and left represents the end of division). B. Telotroch or bud of *Vorticella*. C. Sexual reproduction. 1. Formation of macro- and microzooids. 2. A macrozooid approached by three microzooids. 3. Fusion of a microzooid with a macrozooid.

Asexual reproduction takes place by means of usually unequal *longitudinal binary fission*. During division the body shortens and its nuclei divide first. The macronucleus divides amitotically and micronucleus divides mitotically. The bell divides into two halves by a vertical constriction which begins in the middle of the free end. One of the halves develops a basal circlet of cilia and separates forming a new free living individual. After some time it fixes itself by means of a short adhesive disc called *scopula*. From the scopula a new stalk arises and the individual metamorphoses into adult. The free-swimming stage is called *telotroch*. Sometimes vorticella grows a posterior circlet of cilia and detaches from the stalk to lead a free swimming life.

Sexual reproduction is performed by conjugation. As gametes are of unequal sizes the reproduction is called *anisogamy*. Each individual divides thrice forming eight microzooids. The microzooids swim about by means of posterior girdle of cilia. It differs from telotroch in being much smaller in size. The microzooids survive only for 24 hours and must conjugate with macrogamete within the period. The stationary macrogamete resembles the normal form. It is able to attract the microgamete for two hours. The microgamete during conjugation fixes itself on the lower part of the macrogamete. The macronuclei of both the gametes disappear and their micronuclei reorganise to form male and female pronuclei. When the partition wall between the two dissolves, the two pronuclei unite to form synkaryon or zygote nucleus. The fertilised individual is called *zygote*. From the zygote develops a new vorticella.

Example of the Phylum Protozoa—*Balantidium coli*

It is the only ciliate that parasitises man and pig.

Habit and Habitat. This largest protozoon of the human intestine inhabits the caecum and ascending colon.

Structure. The body is egg-shaped (Fig. 9.42A). The anterior end is pointed and the posterior end is round. The length of the body is 68–134 micra and width is 44–89 micra. The outer limiting surface, *pellicle* is rigid. Cilia are embedded in longitudinal rows. Near the middle of the frontal extremity the pellicle bears a funnel-shaped depression called *peristome*. The

peristome is provided with an aperture, the *cytostome* at its bottom. The cilia, lining the peristome are larger than the rest of the body cilia. There are two constantly occurring *contractile vacuoles* and a number of *food vacuoles*. The *cytopyge* is an inconspicuous aperture situated at the rear. Embedded in the cytoplasm there are the kidneyshaped *macronucleus* and a very small, rounded *micronucleus* hidden within the concavity of the macronucleus. The trophic forms change to cystic forms (Fig. 9.42B). The cysts are nearly spherical, measuring about 55 × 55 sq. micra and the walls are thick. The individuals during encystment retain *cilia* and are motile.

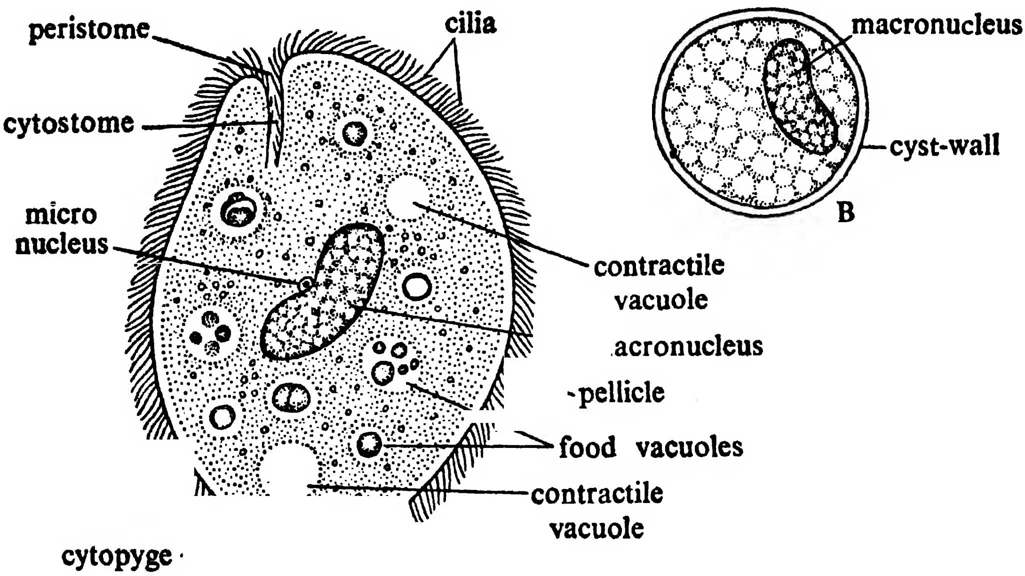


Fig. 9.42. *Balantidium coli* (after Kudo). A. Trophozoite. B. Cyst.

Reproduction. Asexual reproduction occurs by *transverse fission*. It is preceded by mitotic division of the micronucleus and amitotic division of the macronucleus.

Sexual reproduction occurs by *conjugation*. The process resembles that of *Paramoecium* in minute details.

Transmission. Transmission from one host to another occurs in encysted condition through drinking water and contaminated food.

The specific damages done by Balantidium are not known and no more than one-fifth of the infected subjects experiences symptoms. So some observers prefer to consider it as a *commensal.*

The Phylum Protozoa include a large variety of forms. The following tables will give a comparative account of some of the important representatives:

TABLE 6—PROTOZOA

Comparative account of three different members of phylum protozoa

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
1. *Status*	Class—Rhizopodea	Class—Phytomastigophorea	Class—Ciliatea
2. *Habitat*	Lives in fresh water ponds and streams.	Lives in fresh water ponds and streams and prefers to stay in surface water.	Lives in fresh water ponds and streams.

TABLE 6 (contd.)—PROTOZOA

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
3 *Morphology*— (*a*) Shape	Irregular	Fixed, spindle shaped, anterior end broad and posterior pointed.	Fixed, cigar-shaped, anterior end broad and posterior end pointed.
(*b*) Size	About 0·25 mm in diameter.	40–65 μ along the long axis.	Can be seen with naked eyes. 0·25 mm. along the long axis.
(*c*) Limiting membrane	Plasmalemma—thin and elastic.	Pellicle, thin, elastic and bears parallel thickening running obliquely.	Pellicle, thin, elastic and with pores for the emergence of cilia.
(*d*) Cytoplasmic differentiation	Ectoplasm clear and non granular compared to endoplasm.	Ectoplasm is less dense than the endoplasm.	Ectoplasm non-granular and bears 'Trichocysts', endoplasm denser in nature.
(*e*) Cytoplasmic inclusions and organella	Grains of sand and granules which are protein and fat in nature. Single round contractile vacuole, food vacuoles and water vacuoles.	Stored reserve include lipid and paramylum, chlorophyll bearing 'chromatophores' of variable sizes and number. Cytostome funnel-shaped and situated at the anterior end, a gullet joins it to a reservoir into which opens minute contractile vacuoles. Food vacuole usually absent, a single active flagellum and stigma.	Reserve food is the only cytoplasmic inclusion. An oral groove leads into the cytopharynx or gullet. A pair of star-shaped contractile vacuole one each at the anterior and posterior end. Food vacuoles one to many, temporary cell anus and many cilia round the body.
(*f*) Nucleus	Single, lodged centrally in the endoplasm.	Single oval nucleus situated a little below the middle line of the body.	Dimorphic, a bean-shaped macronucleus and a small round micronucleus.
4. *Physiology* (*a*) Locomotion	By protrusion of finger-like projections called Pseudopodia, movement is called Amoeboid movement.	Swims in water in a spiral path with the help of flagellum. It may show 'Euglenoid movement' in which waves of contraction pass along the body like peristaltic movement.	Swims in water in a zig-zag fashion with the concerted beating of cilia.

TABLE 6 (contd.)—PROTOZOA

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
(*b*) Nutrition	Holozoic. Diatom, bacteria, small protozoa serve as food. Food is digested in temporary food-vacuoles. Undigested food particles are thrown out.	Holophytic — it can manufacture its own food. Holozoic and saprophytic modes of nutrition are also exhibited.	Holozoic. The cilia help in drawing food particles in the gullet. Digestion in temporary food-vacuoles. Presence of cytopyge or temporary cell-anus for egestion.
(*c*) Respiration	O_2 dissolved in water enters the body by diffiusion.	Same as in amoeba.	Same as in amoeba.
(*d*) Excretion	Large part of excretory matters in the form of urea and CO_2 pass out through general body surface.	CO_2, urea passes out through general body surface.	CO_2, urea passes out through general body surface.
(*e*) Reproduction	Binary fission is the usual mode. Cyst formation in unfavourable condition.	Longitudinal binary fission is the mode. Binary fission in cyst condition is also encountered.	Asexual reproduction by transverse binary fission. Sexual reproduction by conjugation. No cyst formation.
(*f*) Response to stimuli	React to various kinds of stimuli—namely contact, heat, electricity, light, chemicals, etc.	React to various kinds of stimuli.	React to various kinds of stimuli.

TABLE 7—PROTOZOA

Comparative account of two human parasitic protozoa

POINTS	ENTAMOEBA HISTOLYTICA	PLASMODIUM VIVAX
1. Status	Class—Rhizopodea	Class—Toxoplasmea
2. Disease caused	Amoebiasis leading to ulcer.	Benign tertian malaria.
3. Habitat	In the colon of man and many vertebrates. This intercellular parasite invades other vital organs in case of heavy infection.	Inside the red blood corpuscle and liver parenchymal cells of man. Sexual forms inside the gut and infective forms (sporozoite) in the salivary gland of female Anopheles mosquito.

TABLE 7 (contd.)—PROTOZOA

POINTS	ENTAMOEBA HISTOLYTICA	PLASMODIUM VIVAX
4. Structure	Exists in two forms—trophic and cystic. Trophic forms measure 20–30 micra. Nucleus in stained preparations shows a central endosome and peripheral granules near the membrane. Nucleus measures 3–6 micra. Pseudopodia occur as blunt projections. Food vacuoles contain haemoglobin, cysts measure 6–20 micra. Nucleus of the cyst measures 3–6 micra. Glycogen and chromatoid bars as reserve food occur in cysts.	Appear different at different stages. Sporozoites which are introduced into the blood stream are slender and spindle-shaped having small nucleus. Inside RBC the sporozoites become transformed into Trophozoites. Trophozoites appear as rings having a cavity inside or they may assume amoeboid shape. Often refractile light brown pigments are found in their cytoplasm. Merozoites are small and some of the merozoites give rise to gametocytes. Male gametocytes are small, measure 6–8 micra and take light stain. They undergo exflagellation. Female gametocytes measure 8–10 micra and take deep stain.
5. Reproduction	Trophic forms become encysted. The nucleus of the cyst divides twice forming a tetra-nuclear cyst. After breaking the cyst wall in the intestine of another man eight trophic individuals are formed. Excystment occurs in 12–18 hours time. There is no sexual reproduction.	Reproduction is very complicated. Asexual reproduction in man through Schizogony and Merogony. Sexual reproduction through anisogamy followed by sporogony occurs in mosquito. There is no cyst formation.
6. Transmission	Cysts come out along with the faeces of infected man. Fly carries the cysts from faeces to food of human beings or man becomes infected by drinking contaminated water.	Transmission occurs through the bite and introduction of sporozoites in the blood stream of man by female Anopheles mosquito. Gametocytes develop in the gut of mosquito. After fertilisation the ookinete undergoes sporogony. Sporozoites take shelter in the salivary gland of mosquito and are introduced into the blood stream during biting.

TABLE 8—PROTOZOA

Comparative account of locomotion and its mechanism in three free-living forms of protozoa

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
1. Locomotor structures	Pseudopodia—which are temporary extrusions of	A single, permanent vibratile thread-like structure called	Numerous, permanent small vibratile structures called cilia

TABLE 8 (contd.)—PROTOZOA

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
	ectoplasm in which endoplasm flows later. They may be produced from any point of the body.	flagellum which is always fixed in position.	arranged in rows along the entire body length. About 2,500 cilia may occur in a single individual.
2. Source of Locomotory structures	Ectoplasm is the seat in which endoplasm flows later.	Ectoplasm.	Ectoplasm.
3. Appearance	Pseudopodium appears as a blunt small projection, the outer covering of the projection is formed by the stretched plasmalemma. A hyaline cap is beneath the membrane. The cap is followed by plasmagel and plasmasol parts of the endoplasm.	There are two unequal flagella, of which the shorter inactive one is attached to the longer one. The longer flagellum appears as a long whip-like structure. It originates from a basal granule called blepharoplast and projects out of the anterior end of the body. It consists of an inner core called 'Axoneme' formed by one to three fibrils which are covered by a thin protoplasmic sheath.	Structurally, the cilia are similar to the flagella but they are short, many in number and distributed all over the body. Like the flagellum, a cilium consists of a 'sheath' and an 'Axoneme' which starts from a basal granule. According to some the cilia bear at its tip an end organ which is an argentophilic granule.
4. Nature of movement	Creeping — this is dependent upon a direct contact with the substratum. Movement with the help of Pseudopodia is called 'Amoeboid movement'.	Swimming with the help of flagellum when periodical loss of flagellum occurs it crawls along the substratum and this crawling is called 'Euglenoid movement'.	Swimming by a concerted movement of cilia.
5. Mechanism involved in locomotion	To understand this the body of the amoeba may be divided into four parts, a centrally elongated portion called plasmasol—covered by plasmagel on all sides. The elastic plasmalemma and a hyaline cap between	The flagellum produces rotation of the organism on its major axis and a gyration about an axis for maintaining direction. Waves pass along the flagellum spirally and with progressive increase of amplitude from base	Co-ordinated movement of cilia is responsible in the mechanism. The principle of screw or propeller holds good but the difference is that the beating of cilia contributes a major forward component of force in

TABLE 8 (contd.)—PROTOZOA

POINTS	AMOEBA	EUGLENA	PARAMOECIUM
	plasmalemma and plasmagel. The mechanisms of formation of pseudopodium involves an attachment to the substratum, gelation of the plasmosol at the anterior end, solation of the plasmagel at the posterior end and contraction of the plasmagel at the posterior end.	to tip resulting two component forces. The resultant of these two forces cause rotation and gyration. In principle the propulsion is like that of screw or propellant movement.	addition to rotation and gyration. A spiral path is followed during swimming.

CLASSIFICATION

From the studies of various types which are discussed as examples of the phylum, it is evident that these single-celled animals may be of varied forms. Figure 9.43 illustrates some interesting representatives of the phylum.

The following is a revised scheme of classification of Protozoa which incorporates the results of recent research findings. In preparing this revised scheme, refinement of cytological and microscopical techniques and the contribution of electron microscopic findings, which added new dimensions to the study of Protozoa, have been taken into consideration.

The following classification is based on Honigberg Report ((*J. Protozool.*, 11, 7–20, 1964) and Corliss, 1967 (*Chemical Zoology*, 1, 1–20, Academic Press).

CLASSIFICATION IN OUTLINE. It is subdivided into four subphyla—*Sarcomastigophora*, *Sporozoa*, *Cnidospora* and *Ciliophora*.

PHYLUM PROTOZOA

I. SUBPHYLUM SARCOMASTIGOPHORA

A. *Superclass* MASTIGOPHORA

(*i*) CLASS **Phytomastigophorea**

Order *Chrysomonadida*, e.g. *Ochromonas*

Order *Silicoflagellida*, e.g. *Dictyocha*

Order *Coccolithophorida*, e.g. *Coccolithus*

Order *Heterochlorida*, e.g. *Heterochloris*

Order *Cryptomonadida*, e.g. *Cryptomonas*

Order *Dinoflagellida*, e.g. *Noctiluca*

Order *Ebriida*, e.g. *Ebria*

Order *Euglenida*, e.g. *Euglena*

Order *Chloromonadida*, e.g. *Gonyostomum*

Order *Volvocida*, e.g. *Volvox*

(*ii*) CLASS **Zoomastigophorea**

Order *Choanoflagellida*, e.g. *Proterospongia*

Order *Bicosoecida*, e.g. *Bicosoeca*

Order *Rhizomastigida*, e.g. *Dimorpha*

Order *Kinetoplastida*, e.g. *Trypanosoma*

Order *Retortamonadida*, e.g. *Retortamonas*

Order *Diplomonadida*, e.g. *Giardia*

Order *Oxymonadida*, e.g. *Oxymonas*

Order *Trichomonadida*, e.g. *Trichomonas*

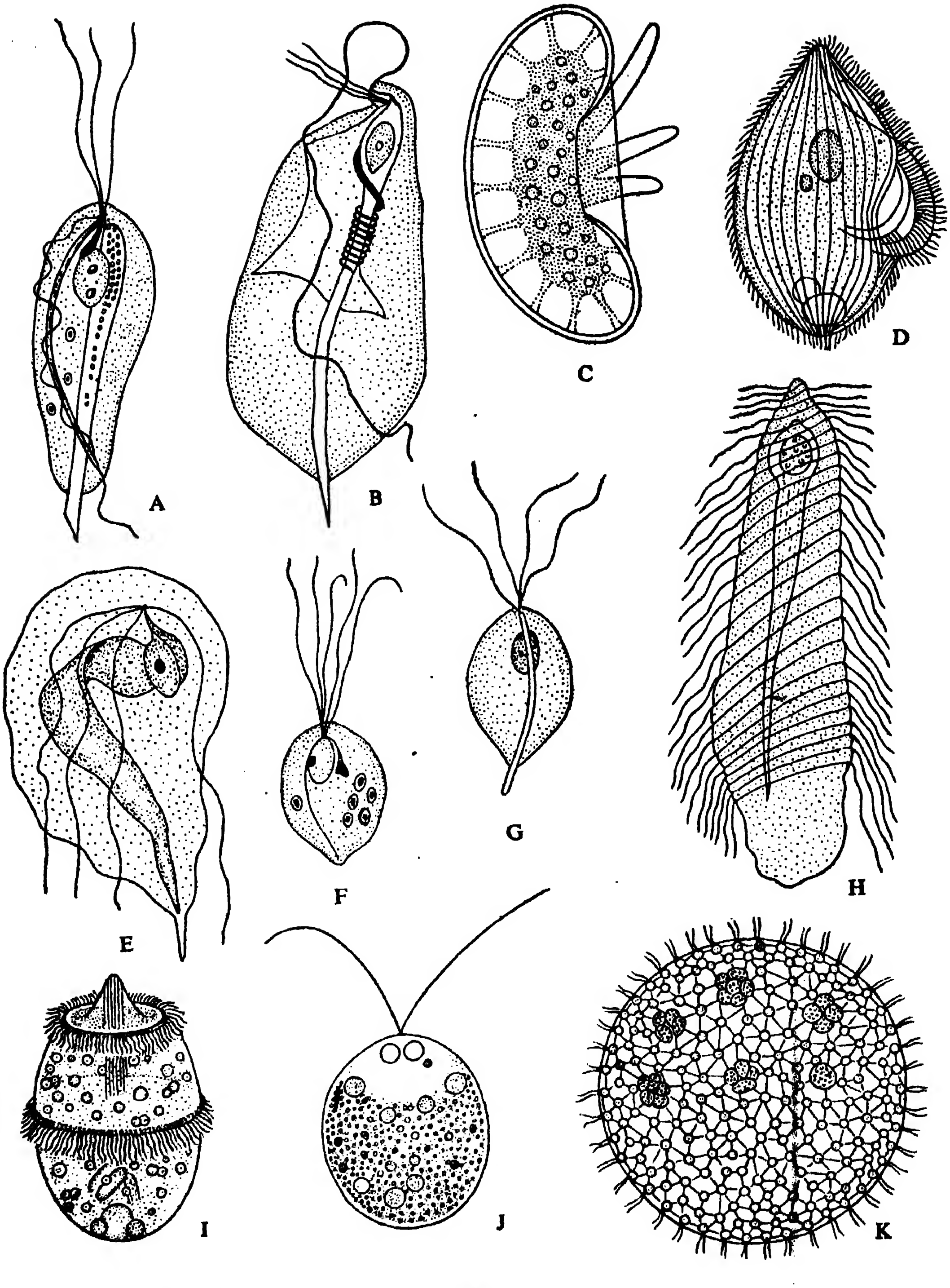


Fig. 9.43. A few examples of Phylum Protozoa (after various sources).

A. *Tritrichomonas augusta*. B. *Macrotrichomonas lighti*. C. *Arcella vulgaris*. D. *Belpharisma lateritium*. E. *Saccinobaculus doroaxostylus*. F. *Hexamastix termopsidis*. G. *Monocercomonas verrens*. H. *Holomastigotoides hemigymnum*. I. *Didinium* sp. J. *Chlamydomonas* sp. K. *Volvox* colony.

Order *Hypermastigida*, e.g. *Lophomonas*

B. *Superclass* OPALINATA

Order *Opalinida*, e.g. *Opalina*

C. *Superclass* SARCODINA

(*i*) CLASS **Rhizopodea**

1. *Subclass* Lobosia

Order *Amoebida*, e.g. *Amoeba*

Order *Arcellinida*, e.g. *Arcella*

2. *Subclass* Filosia

Order *Aconchulinida*, e.g. *Penardia*

Order *Gromiida*, e.g. *Gromia*

3. *Subclass* Granuloreticulosia

Order *Athalamida*, e.g. *Biomyxa*

Order *Foraminiferida*, e.g. *Elphidium*

Order *Xenophyophorida*, e.g. *Stannoma*

4. *Subclass* Mycetozoia

Order *Acrasida*, e.g. *Dictyostelium*

Order *Eumycetozoida*, e.g. *Physarum*

Order *Plasmodiophorida*, e.g. *Plasmodiophora*

5. *Subclass* Labyrinthulia

Order *Labyrinthulida*, e.g. *Labyrinthula*

(*ii*) CLASS **Piroplasmea**

Order *Piroplasmida*, e.g. *Babesia*

(*iii*) CLASS **Actinopodea**

1. *Subclass* Radiolaria

Order *Porulosida*, e.g. *Bathysphaera*

Order *Oculosida*, e.g. *Cystidium*

2. *Subclass* Acantharia

Order *Acanthometrida*, e.g. *Acanthometron*

Order *Acanthophractida*, e.g. *Challengeron*

3. *Subclass* Heliozoia

Order *Actinophryida*, e.g. *Actinophrys*

Order *Centrohelida*, e.g. *Acanthocysitis*

Order *Desmothoracida*, e.g. *Clathrulina*

4. *Subclass* Proteomyxidia

Order *Proteomyxida*, e.g. *Leptomyxa*

II. SUBPHYLUM SPOROZOA

(*i*) CLASS **Telosporea**

1. *Subclass* Gregarinia

Order *Archigregarinida*, e.g. *Selenidium*

Order *Eugregarinida*, e.g. *Monocystis*

Order *Neogregarinida*, e.g. *Ophryocystis*

2. *Subclass* Coccidia

Order *Protococcida*, e.g. *Eucoccidium*

Order *Eucoccida*, e.g. *Eimeria*

(*ii*) CLASS **Toxoplasmea**

Order *Toxoplasmida*, e.g. *Toxoplasma*

(*iii*) CLASS **Haplosporea**

Order *Haplosporida*, e.g. *Haplosporidium*

III. SUBPHYLUM CNIDOSPORA

(*i*) CLASS **Myxosporidea**

Order *Myxosporida*, e.g. *Leptotheca*

Order *Actinomyxida*, e.g. *Triactinomyxon*

Order *Helicosporida*, e.g. *Helicosporidium*

(*ii*) CLASS **Microsporidea**

Order *Microsporida*, e.g. *Nosema*

IV. SUBPHYLUM CILIOPHORA

(*i*) CLASS **Ciliatea**

1. *Subclass* Holotrichia

Order *Gymnostomatida*, e.g. *Didinium*

Order *Trichostomatida*, e.g. *Balantidium*

Order *Chonotrichida*, e.g. *Spirochona*

Order *Apostomatida*, e.g. *Foettingeria*

Order *Astomatida*, e.g. *Anoplophrya*

Order *Hymenostomatida*, e.g. *Tetrahymena*, *Paramoecium*

Order *Thigmotrichida*, e.g. *Ancistrocoma*

2. *Subclass* Peritrichia

Order *Peritrichida*, e.g. *Vorticella*

3. *Subclass* Suctoria

Order *Suctorida*, e.g. *Podophrya*

4. *Subclass* Spirotrichia

Order *Heterotrichida*, e.g. *Spirostomum*

Order *Oligotrichida*, e.g. *Halteria*

Order *Tintinnida*, e.g. *Tintinnidium*

Order *Entodiniomorphida*, e.g. *Entodinium*

Order *Odontostomatida*, e.g. *Discomorphella*

Order *Hypotrichida*, e.g. *Aspidisca*

CLASSIFICATION WITH CHARACTERS

SUBPHYLUM SARCOMASTIGOPHORA

Locomotory structures are present either in the form of flagella, pseudopodia or both. Nucleus is usually of single type (excepting the developmental stages of certain Foraminiferida). No spore formation. Sexual reproduction when present is through syngamy. It includes three superclasses—*Mastigophora*, *Opalinata* and *Sarcodina*.

Superclass MASTIGOPHORA

Either solitary or colonial. Presence of one or more flagella in trophozoite stage. Sexual reproduction is uncommon. Nutrition may be either phototrophic or heterotrophic or both. It is subdivided into two classes—*Phytomastigophorea* and *Zoomastigophorea*.

CLASS **Phytomastigophorea**

Usually possess chromatophores which may be secondarily lost. Presence of one or two emergent flagella. In some groups amoeboid forms occur. Most members are free living and certain forms exhibit sexual reproduction. There are ten orders in this class.

Order *Chrysomonadida*

Presence of one to three flagella. One or two yellow or yellow green or brown-coloured chromatophores are usually present. Amoeboid stages are frequent. Food reserves are present as leucosin and lipids. Cyst wall is always siliceous, e.g. *Ochromonas*, *Chromulina*.

Order *Silicoflagellida*

Flagellum is either absent or only one. Chromatophores are brown coloured. Inner skeleton is made up of silica, e.g. *Dictyocha*, *Clathropyxidella*.

Order *Coccolithophorida*

Flagella and chromatophores are always two in number. Presence of calcareous plates as external covering. Usually marine, e.g. *Discoaster*, *Coccolithus*.

Order *Heterochlorida*

Two flagella are of unequal length. Yellow green-coloured chromatophores vary from two to several. Usually amoeboid forms are present. Lipids are common food reserves. Walls of cysts are made up of silica, e.g. *Heterochloris*, *Rhizochloris*.

Order *Cryptomonadida*

Body is compressed. Two flagella usually originate from a depression. Chromatophores are two and usually brown but may be red, olive green or blue green in colour. Amoeboid stages are

absent. Starch and amyloid bodies are the usual food reserves, e.g. *Chilomonas*, *Cryptomonas*.

Order *Dinoflagellida*

Body is divided into girdle and sulcus by transverse and longitudinal grooves. Each part contains a flagellum. Of these two flagella, one is transverse and the other is trailing. Chromatophores are either yellow or dark brown, but may be green or blue green. A theca is present in many forms. Reserve foods are starch and lipids, e.g. *Noctiluca*, *Gymnodinium*.

Order *Ebriida*

Chromatophores are absent and usually with two flagella. Internal skeleton is siliceous, e.g. *Ebria*.

Order *Euglenida*

One or two flagella arise from an anterior reservoir. Chromatophores are green and their shapes may vary. Though body form may change yet no amoeboid movement occurs. Food reserves are present as paramylum, e.g. *Euglena*, *Peranema*.

Order *Chloromonadida*

Two flagella originate from the side of a superficial apical cleft or furrow. Body is dorsoventrally flattened. Chromatophores are green and numerous. Food reserves are present as lipids and glycogen, e.g. *Gonyostomum*.

Order *Volvocida*

Either solitary or colonial. Flagella are two to four and apical. Chromatophores, when present, are leaf green. Appearance more or less like a shell or cup. Amoeboid forms usually absent. Food reserves in the form of starch, e.g. *Pandorina*, *Volvox*.

Class **Zoomastigophorea**

Usually live in association. Chromatophores are absent. Presence of one to many flagella. Amoeboid forms, when present, may not have flagella. It includes nine orders.

Order *Choanoflagellida*

Free living and may be solitary or colonial. A peduncle for attachment may be present in some forms. Flagellum is single, anteriorly placed and enclosed posteriorly by a thin collar, e.g. *Proterospongia*, *Codosiga*.

Order *Bicosoecida*

Free living, with two flagella—one is free and the other is attached to the posterior end, e.g. *Bicosoeca*, *Poteriodendron*.

Order *Rhizomastigida*

Usually free living. Flagella and pseudopodia occur either at the same time or at different times, e.g. *Dimorpha*, *Histomonas*.

Order *Kinetoplastida*

Most members live in association. Number of flagella varies from one to four. A self-replicating, Feulgen positive organella called Kinetoplast is present, e.g. *Trypanosoma*, *Leishmania*, *Herpetomonas*.

Order *Retortamonadida*

Usually live in association. Presence of a ventral cytostome with fibrillar border. Number of flagella ranges from two to four, and one of them is turned posteriorly to remain attached with cytostomal region, e.g. *Retortamonas*, *Chilomastix*.

Order *Diplomonadida*

Most members live in association. Body is bilaterally symmetrical and possesses two karyomastigonts each having four flagella and set of accessory organelles, e.g. *Giardia*.

Order *Oxymonadida*

Presence of one or more karyomastigonts, each having two pairs of flagella. A few flagella are turned posteriorly and attach for some distances to the body surface. Axostyles vary from one to many, e.g. *Oxymonas*, *Pyrsonympha*.

Order *Trichomonadida*

Presence of four to six flagella. Undulating membrane, when present, is associated with recurrent flagellum. Axostyle and parabasal apparatus are present. Spindle during division is extranuclear. Sexual reproduction and cyst formation are absent. Usually live in association, e.g. *Trichomonas*, *Tritrichomonas*.

Order *Hypermastigida*

Presence of six multiple flagella and

numerous parabasal apparatus. Kinetosomes are distributed in various ways and meet anteriorly in a central structure. Uninucleated and extranuclear spindle formation occurs during division. Occurrence of sexual reproduction is observed in some forms, e.g. *Lophomonas*, *Trichonympha*.

Superclass OPALINATA

It includes a single order *Opalinida*.

Order *Opalinida*

Presence of cilium-like organelles in oblique rows over entire body surface. Cytostome is absent, more than one nucleus of same type. Sexual reproduction happens through the production of anisogamous flagellated gametes. Always live in association, e.g. *Opalina*, *Zelleriella*.

Superclass SARCODINA

Usually free living. Locomotor organella in the form of pseudopodia. Flagella appear in some forms during development. Cortical cytoplasm is undifferentiated. Body may or may have various types or exo- or endo-skeleton. Asexual reproduction occurs by fission. Sometimes sexual reproduction with flagellate or amoeboid gametes is noted. The members of this superclass are again subdivided into three classes—*Rhizopodea*, *Piroplasmea* and *Actinopodea*.

Class **Rhizopodea**

Nutrition is phagotrophic. Pseudopodia may be lobopodia, filopodia or reticulopodia. Five subclasses—*Lobosia*, *Filosia*, *Granuloreticulosia*, *Mycetozoia* and *Labyrinthulia*.

Subclass Lobosia

Locomotion by characteristic lobose type of pseudopodia, occasionally becoming filiform or anastomosing. It consists of the orders, *Amoebida* and *Arcellinida*.

Order *Amoebida*

Uninucleate and without any covering. Majority are free living, e.g. *Amoeba*, *Pelomyxa*, *Entamoeba*, *Chaos*.

Order *Arcellinida*

Free living forms having a test or rigid membranes. Pseudopodia protrude through definite aperture, e.g. *Arcella*, *Difflugia*.

Subclass Filosia

Filopods are tapering and branching but the branches rarely anastomose. Two orders, *Aconchulinida* and *Gromiida* are included within this subclass.

Order *Aconchulinida*

Filosia with naked body, e.g. *Penardia*.

Order *Gromiida*

Presence of test with definite aperture. Certain members possess uniflagellate gametes, e.g. *Gromia*, *Euglypha*.

Subclass Granuloreticulosia

Pseudopods are thin, reticular and granular. Three orders, *Athalamida*, *Foraminiferida* and *Xenophyophorida* are present within this subclass.

Order *Athalamida*

Without any test and pseudopodia may originate from any part of the body, e.g. *Biomyxa*.

Order *Foraminiferida*

Presence of a test having one or more chambers. Pseudopodia appear from aperture or perforations or both. Life cycle involves definite alteration of sexual and asexual forms. Gametes are with flagella and sometimes they may be amoeboid. Presence of sexual dimorphism in some, e.g. *Elphidium*, *Rosalina*.

Order *Xenophyophorida*

Body is multinucleated plasmodium and network of pseudopodia passes through a hollow organic tube. Many foreign particles are present in the interstices of pseudopodial network, e.g. *Stannoma*.

Subclass Mycetozoia

Trophic amoeboid forms either form an aggregate or a multinucleate plasmodium. Complicated life cycle involves sexual reproduction and ends in sporangia form. Spore gives rise to amoeboid form. Nutrition may be heterotrophic or osmotrophic. This subclass includes three orders—*Acrasida*, *Eumycetozoida* and *Plasmodiophorida*.

Order *Acrasida*

Never forms true plasmodium. Flagellated stage is absent. Free living. No sexual reproduction occurs, e.g. *Dictyostelium*.

Order *Eumycetozoida*

Free living and occurrence of flagellated stages. Presence of true plasmodium and typical sporangia with peridia and capillitia, e.g. *Physarum*, *Ceratiomyxa*.

Order *Plasmodiophorida*

Live in association with plants. Occurrence of large plasmodium with host tissue. Presence of flagellated stages. Sporangia without peridia and capillitia, e.g. *Plasmodiophora*.

Subclass Labyrinthulia

Only one order Labyrinthulida represents the subclass.

Order *Labyrinthulida*

Individuals are spindle-shaped and form a net along filamentous tracks. Either live on marine plants or in soil. True amoeboid stage lacking, e.g. *Labyrinthula*.

Class **Piroplasmea**

It includes a single order *Piroplasmida*.

Order *Piroplasmida*

Small forms of various shapes. Spores, flagella, cilia are absent. Locomotion by gliding. Binary fission takes place. Lives as parasite in vertebrate blood and are carried by ticks, e.g. *Theileria*, *Babesia*.

Class **Actinopodea**

Usually floating with spherical body and delicate pseudopodia. Pseudopodia may be axopodia, filose or reticulate. Usually naked, when test present it is either membraneous or chitinoid or silicious or strontium. Both asexual and sexual reproduction occur. Gametes are flagellated. There are four subclasses, *Radiolaria*, *Acanthacia*, *Heliozoia* and *Proteomyxida*.

Subclass Radiolaria

Marine forms having one to many pores in the central capsule. Presence of siliceous spicules or skeleton. Locomotor organella is either filopod or reticulopod or axopod. Two orders, *Porulosida* and *Oculosida* are included within this subclass.

Order *Porulosida*

The round central capsule has pores all around, e.g. *Pipetta*, *Thalassicolla*.

Order *Oculosida*

The central capsule has pores only at one pole, e.g. *Cystidium*, *Eucyrtidium*.

Subclass Acantharia

Thin central capsule with membraneous poreless covering. Strontium sulphate forms regularly oriented radial spines. Pseudopodia as axopod. All are marine. Two orders included are—*Acanthometrida* and *Acanthophractida*.

Order *Acanthometrida*

Rod-like skeleton are without lattice shell, e.g. *Acanthometron*.

Order *Acanthophractida*

Skeleton is completely latticed, e.g. *Challengeron*.

Subclass Heliozoia.

Central capsule is absent. Sometimes skeletons are present as siliceous scales or spines, but usually naked. Locomotion through axopods or filopods. Most of the members are fresh water. It has three orders—*Actinophryida*, *Centrohelida* and *Desmothoracida*.

Order *Actinophryida*

Skeleton and centroplast are absent, e.g. *Actinophrys*, *Actinosphaerium*.

Order *Centrohelida*

Centroplast is present and plate or spine like skeletons are siliceous, e.g. *Acanthocysitis*.

Order *Desmothoracida*

Centroplast is absent. Chitinous skeleton has siliceous impregnation, e.g. *Clathrulina*.

Subclass Proteomyxidia

Order *Proteomyxida*

Only a few forms are free living. No test, filopodia, reticulopodia, flagellated forms and cysts are seen in some cases, e.g. *Pseudospora*, *Leptomyxa*.

Subphylum SPOROZOA

Simple spores without polar filaments carry one to many sporozoites. Cilia always absent but flagellated gametes may occur. Sexual reproduction, when occurs, is syngamous. All the forms live in association. It is subdivided into three classes —*Telosporea*, *Toxoplasmea* and *Hoplosporea*.

Class Telosporea

Spores are seen. Both asexual and sexual reproduction take place. Locomotion by gliding or body flexion. Pseudopodia are usually absent but sometimes used only for food capture. Microgametes are flagellated in some. Two subclasses *Gregarinia* and *Coccidia* are included in this class.

Subclass Gregarinia

Live as extracellular parasites in the digestive tract and body cavity of invertebrates. It consists of three orders—*Archigregarinida*, *Eugregarinida* and *Neogregarinida*.

Order *Archigregarinida*

Presence of three schizogony. Live as parasites of ascidians, enteropneusids, sipunculids and annelids, e.g. *Selenidium*.

Order *Eugregarinida*

Live as parasites of annelids and arthropods and have no schizogony, e.g. *Monocystis*, *Gregarina*, *Nina*.

Order *Neogregarinida*

Presence of secondary schizogony. Lives as parasite of insects, e.g. *Ophryocystis*.

Subclass Coccidia

Always live as intracellular parasite and have small trophozoites. Two orders, *Protococcida* and *Eucoccida* are present in this subclass.

Order *Protococcida*

Parasites of marine annelids and do not have schizogony, e.g. *Eucoccidium*.

Order *Eucoccida*

Live as parasite in epithelial and blood cells of invertebrates and vertebrates. Presence of schizogony. Alternation of asexual and sexual phases in life cycle, e.g. *Eimeria, Plasmodium*.

Class Toxoplasmea

Single order *Toxoplasmida* is present within the class.

Order *Toxoplasmida*

No spore formation. Asexual reproduction occurs by binary fission. Locomotion is effected through gliding or body flexion. Structures like pseudopodia and flagella are absent. Cysts include naked trophozoites, e.g., *Toxoplasma, Sarcocystis*.

Class Haplosporea

It includes only one order *Haplosporida*.

Order *Haplosporida*

Presence of spores, only asexual reproduction takes place. Schizogony is present. Though pseudopodia may appear in some cases, yet flagella are absent, e.g. *Haplosporidium*, *Coelosporidium*.

Subphylum CNIDOSPORA

Presence of spores having one or more spore filaments and sporoplasms. All the members live as parasite. Two classes—*Myxosporidea* and *Microsporidea* are present within this subphylum.

Class Myxosporidea

Multicellular state gives rise to spore. Presence of one or more sporoplasms and more than one valve. It comprises of three orders—*Myxosporida*, *Actinomyxida* and *Helicosporida*.

Order *Myxosporida*

Presence of one or two sporoplasms and one to six polar capsules. Each capsule having a coiled polar filament for anchoring. Spore membrane may have up to six valves. Live as parasite in poikilothermal vertebrates, e.g. *Leptotheca*, *Myxidium*.

Order *Actinomyxida*

Presence of three polar capsules in a spore. Each capsule is with a polar filament. Three valves are present in the membrane. Many sporoplasms occur. Live in annelids and other invertebrates, e.g. *Triactinomyxon*.

Order *Helicosporida*

Three sporoplasms in a spore are enclosed by coiled thick filament. Spore membrane possesses one valve. Parasites in insects, e.g. *Helicosporidium*.

Class Microsporidea

Order *Microsporida*

Spores originate from a single cell. Presence of single sporoplasm, valve and an elongated tubular polar filament. Parasites in invertebrates, e.g. *Caudospora*, *Nosema*.

Subphylum *Ciliophora*.

A single class *Ciliatea*, constitutes the subphylum.

Class **Ciliatea**

Free living forms with cilia or ciliated organelle at least in some part of the life cycle. Subpellicular infra-ciliature always present, even during the absence of cilia. Usually two types of nuclei are seen. Both asexual and sexual reproductions occur. Sexual reproduction involves either conjugation or autogamy or cytogamy. Nutrition is heterotrophic. It is divided into four subclasses—*Holotrichia*, *Peritrichia*, *Suctoria* and *Spirotrichia*.

Subclass Holotrichia

Ciliature on the surface is uniform and simple. Buccal ciliature present only in a few cases. It includes seven orders—*Gymnostomatida*, *Trichostomatida*, *Chonotrichida*, *Apostomatida*, *Astomatida*, *Hymenostomatida* and *Thigmotrichida*.

Order *Gymnostomatida*

Larger-sized forms with no oral ciliature. Cytostome communicates directly to the outside. Presence of rods in the cytopharyngeal wall, e.g. *Didinium*, *Urotricha*.

Order *Trichostomatida*

Generally body ciliation is uniform but may be asymmetrical in some cases. No buccal ciliation in oral area, e.g. *Balantidium*, *Colpoda*.

Order *Chonotrichida*

Body ciliature absent in mature forms which are vase-shaped and cling to the crustacean body by means of non-contractile stalk. Reproduction is asexual and by budding, e.g. *Spirochona*, *Chilodochona*.

Order *Apostomatida*

Body ciliature in mature forms is spiral. Cytostome is inconspicuous. Life cycle exhibits polymorphius, e.g. *Foettingaria*, *Polyspira*.

Order *Astomatida*

Body ciliature is uniform. Cytostome is absent. Usually of large size, some having endoskeletons or structures as holdfast. Usually parasites in oligochaetes, e.g. *Anoplophrya*, *Haptophrya*.

Order *Hymenostomatida*

Small-sized forms have uniform body ciliature. Buccal cavity is ventral and presence of one undulating membrane on the right and three membranelles on the left, e.g. *Tetrahymena*, *Paramoecium*.

Order *Thigmotrichida*

Tuft of cilia is present near the anterior end. Buccal ciliature either ventral or posteriorly placed. Usually live in association with bivalve molluscs, e.g. *Ancistrocoma*, *Conchophthirus*.

Subclass Peritrichia

The only order belonging to this subclass is *Peritrichida*.

Order *Peritrichida*

Body ciliature is usually absent in matured forms. Presence of either contractile stalk or adhesive disc for attachment to the substrate. Ciliary arrangement in the oral region is conspicuous. It coils here around apical pole counter-clockwise to cytostome, e.g. *Vorticella*, *Epistylis*.

Subclass Suctoria

It includes a single order *Suctorida*.

Order *Suctorida*

Absence of external ciliature in mature forms. Usually sessile with non-contractile stalk for attachment. Presence of suctorial tentacles for nutrition. Reproduction by budding and larva is free swimming and with external ciliation, e.g. *Podophyra*, *Acineta*.

Subclass Spirotrichia

External ciliature is sparse in most. Presence of cirri in some. Elaborate buccal ciliature. Presence of adoral zone with many membranelles. Oral cilia coil around apical pole in clockwise to cytostome. Six orders—*Heterotrichida*, *Oligotrichida*, *Tintinnida*, *Entodiniomorphida*, *Odontostomatida* and *Hypotrichida* are included within the subclass.

Order *Heterotrichida*

External ciliature is uniform. Large-sized body in some cases bears pigments, e.g. *Stentor*. *Spirostomum*.

Order *Oligotrichida*

External ciliature is absent. Prominent

buccal membranelles are present. Size is small; usually marine, e.g. *Halteria*, *Tontonia*.

Order *Tintinnida*

All with varied coverings called lorica, from where prominent oral membranelles extend. Marine, e.g. *Tintinnus*, *Codonella*.

Order *Entodiniomorphida*

External ciliature is absent. Oral membranelles are restricted. Presence of membranellar tufts or zones. Pellicle is stiff and extended posteriorly in some forms as spine, e.g. *Entodinium*, *Diplodinium*.

Order *Odontostomatida*

Eight membranelles represent oral ciliature. Laterally compressed miniature body sometimes possesses spines on the pellicle, e.g. *Saprodinium*.

Order *Hypotrichida*

Various types of cirri are ventrally placed. Dorso-ventrally flattened body. Membranelles are prominent in adoral zone, e.g. *Aspodisca*, *Gastrostyla*.

GENERAL NOTES ON PROTOZOA

HISTORY. As a group the Protozoa are very old and are inhabiting the earth for about a billion and half years. Fossil forms of Radiolaria and Foraminifera, half a billion years old, have been recorded.

The existence of Protozoa could only be ascertained after the invention of microscopes. Leeuwenhoek (1676) gave preliminary accounts of many forms belonging to this group. Goldfuss (1818) coined the term **Protozoa** without making any specific reference to true Protozoans. The morphology of the Protozoa was for the first time realised after the enunciation of cell-theory (1838–1839). In 1845, Von Siebold recognised the unicellular nature of the Protozoa and established the term 'Protozoa' in its spirit and true sense.

HABITAT. Adaptation of Protozoa is extended to all environments open to micro-organism. Free living forms occur in fresh water lakes, ponds, open ocean, river and even in temporary pools. Soil and sands also form natural environment for many Protozoa. Such Protozoa live in the film of moisture surrounding soil particles or sand grains. Parasitic protozoa occur in many different species of animals, in certain plants and even in a few protozoans themselves. The microsporidian *Nosema notabilis* is a hyperparasite on myxosporidian *Spherospora* (Fig. 9.44). In the body of the animal host they occur in the coelom, digestive tract, individual tissue cells and body fluids. Trypanosomes live in the blood plasma and malarial parasites invade individual red blood cells and liver parenchyma cells and ultimately destroy them. Certain parasitic forms stick to a single kind of host while there are others which can live successfully in a few closely related species of animals or two or more different and unrelated species of hosts. For such Protozoa that can invade unrelated host species, a change of hosts is essential for the

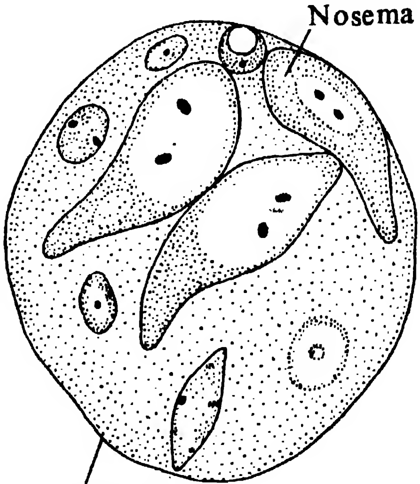


Fig. 9.44. A unique example of hyperparasitism. A trophozoite of *Sphaerospora polymorpha* is infected by trophozoites of *Nosema notabilis* (after Kudo).

completion of its life cycle. Of all the animals, human beings are most hospitable to parasitic protozoa for as many as twenty-five different species of parasitic Protozoa have been encountered in them.

NUMBER. The specific number of different kinds of Protozoa living today is a matter of speculation. It has been estimated that there are about 30,000 species. But this estimation is subject to inaccuracy as many current names of species represent duplication and there are many more yet to be described.

PROTOZOA OR PROTISTA. All the types of nutrition, i.e. holozoic, saprozoic and holophytic are seen in the protozoan group. Flagellates like *Euglena*, contain chlorophyll and carry on photosynthesis like plants. Mycetozoa of protozoologists is the other name of slime molds of botanists (Fig. 9.45). That means they are more plant-like than animal-like and as a result the ordinary criteria for separating plants from animals break down at the level of Protozoa. To avoid unwanted arguments in case of those animals stamped with such mixture of characters some inspired Biologists have proposed a group, *Protista*, to include Protozoa, unicellular algae and other microorganisms.

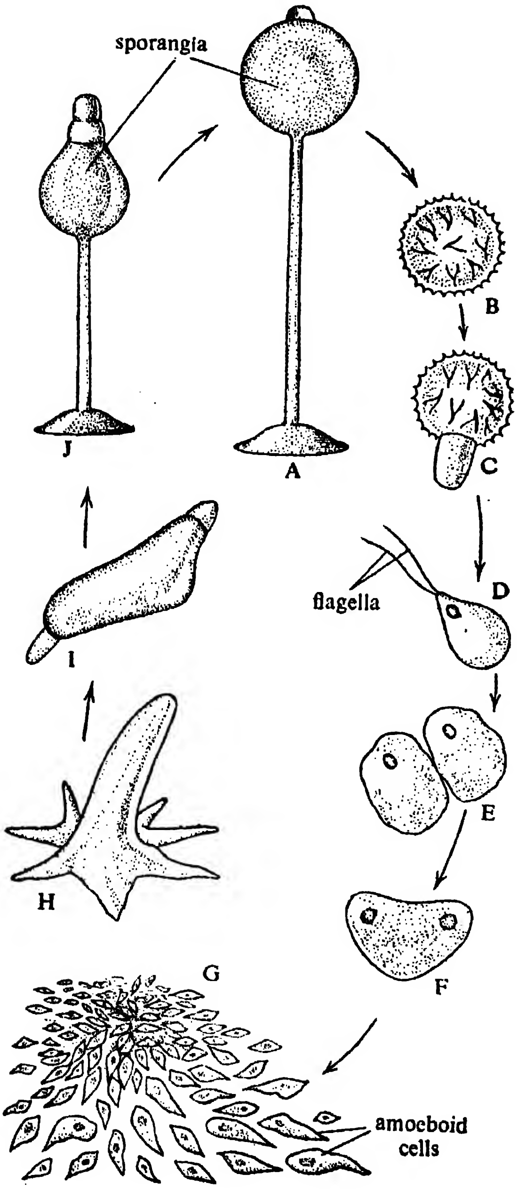


Fig. 9.45. Life cycle of a slime mold, Mycetozoa (after Nason).
A. Fruit body. B. Spore. C. Germinating spore. D. Biflagellated swarm cell (gamete). E. Fusion of swarm cells. F. Zygote. G. Free living amoeboid cells aggregating to form a plasmodium. H, I, J. Stages showing the formation of a fruit body.

Theoretically the scheme has many advantages but in practice the term protista has not been adopted because of proprietary interests of Botanists in Algae, Bacteriologists in Bacteria and Zoologists in Protozoa.

ARCHITECTURE OF PROTOZOA

SHAPE. Excepting a few Rhizopods most Protozoa are with fixed shape and size characteristic for each species. The forms of Protozoa may be flattened, spherical, oval or elongated and often bizzare shapes are also encountered. Though majority of Protozoa exhibit an important bilateral symmetry, all types of animal-symmetry are witnessed in them. Rhizopods and Foraminifera are asymmetrical. Heliozoa and Radiolarians exhibit spherical symmetry while radial symmetry is noted in sessile choanoflagellates, bilateral symmetry is apparent in *Giardia* or *Octomitus*.

SIZE. Most of the Protozoa are microscopic in size and range from 2–4μ to several millimeter in length or diameter. Plasmodium residing within the RBC is considered as the smallest of all Protozoa. Radiolaria and Foraminifera are largest in size amongst the Protozoans. The shells of Foraminifera may attain a diameter of 2–15 mm. *Spirostomum ambiguum* is the largest among fresh water ciliates and is about 4·5 mm in length.

THE CELL BODY. The basic and the fundamental component of the Protozoan body is protoplasm which is differentiated into nucleus, cytoplasm and cell membrane.

A. NUCLEUS. The form, structure and size of Protozoan nucleus are extremely variable (Fig. 9.46). Most Protozoa contain a single nucleus and in many there are two or more. *Giardia* and *Protoopalina* contain two similar and identical nuclei while Euciliates and Suctoria bear dissimilar nuclei, i.e., micronucleus and

macronucleus. This nuclear dimorphism is also present in certain foraminifera. The macronucleus is considered as 'somatic' nucleus performing general metabolic activities while the small one is nucleoplasm. The macronucleus of ciliates is of compact type.

Within the nucleus there are two general kinds of nucleolus-like bodies which contain no DNA and are called 'endosomes'

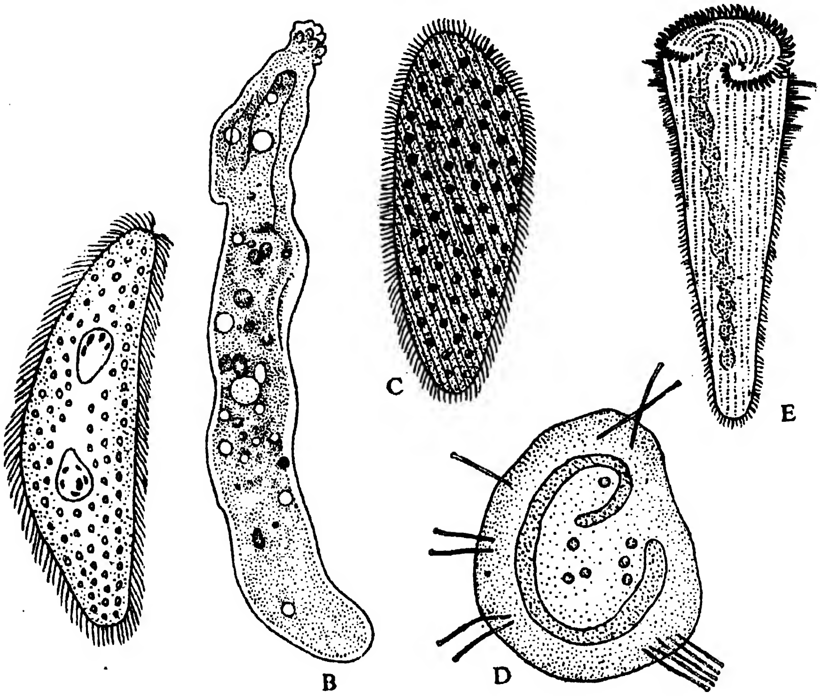


Fig. 9.46. Examples of different types of nuclei in protozoa (after various sources).
A. *Protoopalina* (with two identical nuclei). B. *Pelomyxa* (with numerous nuclei). C. *Opalina* (with numerous small nuclei). D. *Cyclophrya* (possessing dissimilar nuclei). E. *Stentor* and F. *Spirostomum* (both chain-like macronuclei).

considered as 'generative' which looks after the reproductive part. In *Pelomyxa*, *Opalina*, *Myxosporidia* and *Microsporidia* there are numerous similar nuclei. The macronucleus offers variation in its form and structure. It is compact, spherical or ellipsoidal in most cases. In *Vorticella* it is much elongated. In *Spirostomum* and *Stentor*, it is like a chain of nodes joined to one another by filaments. The chromatin of the meganucleus is called *trophochromatin* while that of micronucleus is made up of *idiochromatin*.

Protozoan nucleus may be *vesicular* or *compact*. Vesicular nucleus consists of a nuclear membrane which is very thin and delicate but nucleoplasm is distinct and chromatin content is less. The compact nuclei are always massive as they contain large amount of chromatin substance and a comparatively small amount of or nucleoli. The endosome in Euglenoids is centrally located, made up of three concentric zones and divides during nuclear division. In parasitic amoebae like *Entamoeba* the endosome is composed of a number of irregular masses, each containing numerous small particles and it disappears during mitosis.

Repeated mitoses in the nucleus with no dissolution of nuclear membrane result in some cases in the formation of a *polyenergid nucleus*. Each polyenergid nucleus bears many sets of chromosomes which are finally distributed to the daughter cells. Polyenergic states are believed to be antithesis of sporulation.

B. CYTOPLASM. It is the extranuclear part of the Protozoan body. The cytoplasm is colourless, homogeneous, and in optical observation presents granulated, vacuolated, reticulated or fibrillar texture.

The cytoplasm is differentiated into ectoplasm and endoplasm. The ectoplasm is also called the 'Cortex'. The cortex is hyaline and gelatinous and may be defined as a part of cytoplasm bounded externally by plasma membrane and internally by endoplasm. In Ciliophora, the cortex houses a number of organelles. The endoplasm is voluminous and fluid (Plasmasol).

C. **CELL SURFACE.** The cytoplasm bears a protective envelope which may be present in the following textures:

1. **Plasmalemma.** An extremely thin membrane which regulates the entry and exit of materials between the organism and the surrounding medium in which it lives.

2. **Pellicle.** The surface layer becomes gelated and forms a visible firm pellicle. The pellicle is living and is often sculptured as in *Paramoecium.*

3. **Cuticle.** The outer limiting surface may be a cuticle as in *Monocystis*. The cuticle is dead and may be made up of nitrogenous elements, carbohydrate or cellulose.

4. **Shell.** The whole body may be encased in a close fitting shell having an aperture through which protoplasm may be extruded. The shell is composed of nitrogenous elements in *Arcella*, of silicious plates in *Euglypha* or calcium carbonate as in *Foraminifera.* Cysts are temporary shells with no opening. (See also Figure 9.47 for other types of coverings in Protozoa).

D. **CYTOPLASMIC INCLUSIONS**

1. **Stored food.** Polysaccharides, lipids and rarely nitrogenous materials remain embedded in the cytoplasm. Polysaccharides are present in the form of starch granules, leucosin and paramylum bodies as in *Stentor* and cysts of *Entamoeba*. The synthesis of polysaccharides in *Phytomastigophores* is independent of the presence of chlorophyll. Presence of glycogen has been reported in many *Sarcodina* and *Ciliates*. In some parasitic protozoa glycogen synthesis is stepped up during cyst formation. These glycogens are never identical with the glycogens of other higher animals. A peculiar type of glycogen which is neither typical glycogen nor true starch is encountered in the endoskeletal plates of certain ciliates which live in the rumen of cattle. Histochemical tests have shown that carbohydrate is stored by Amoeba in the form of glycogen. Washed amoeba

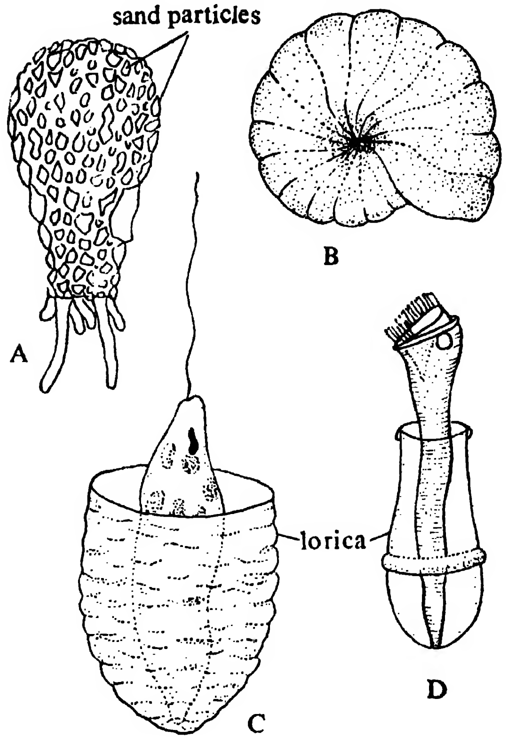


Fig. 9.47. Figure showing different types of coverings in Protozoa (after Hall).
A. *Difflugia* with gelatinous coating on which sand and other foreign particles are attached. B. *Cyclammina*--with spiral shell of calcium carbonate. C. *Klebsiella*-- showing outer covering called Lorica. D. *Vaginicola*—a ciliate with loricate covering.

if treated with radioactive glucose—the isotope is recovered from the Amoebic glycogen.

Lipids, i.e. fat and other related substances, remain stored and distributed throughout the cytoplasm as small globules or in some cases they remain localised in a particular area of the body. This stored oil in some *Phytomastigophora* presents a disagreeable taste and colour.

Nitrogenous reserves as chromatoid bodies of *Entamoeba* are also recognised. They are seen in the cysts and the characteristic forms of chromatoid help in distinguishing one species from the other. The chromatoid bodies are made up of protein and RNA and till date their function is unknown. 'Volutin granules' containing RNA have been reported in many Protozoa.

2. **Mitochondria.** Mitochondria are present in all aerobic species. Number of mitochondria present in an organism are dependent on the volume of that particular organism. In *Tetrahymena* there are many mitochondria while in avian malarial parasite *Plasmodium lophurae* there are one or two mitochondria. Structurally and functionally the Protozoan mitochondria differ very little from that of higher animals. The mitochondria occur as small spherical, oval, rod-shaped or filamentous bodies. They may be evenly distributed in the cytoplasm or may be localised in position as they are arranged between the kinetostomes of cilia in *Opalina* and *Paramoecium*.

3. **Golgi apparatus.** Presence of Golgi bodies in the form of compact, flattened and plate-like vesicles has been reported in *Amoeba* and *Pelomyxa* with certainty.

4. **Cytoplasmic pigments.** Pigment granules of various colours—violet, blue, green, yellow, pink, red occur in the cytoplasm of *phytoflagellates* and *ciliates.* Red pigments occur in *Phytomonadina* and *Euglena.* When exposed to bright light these red pigments increase in number and mask the usual green colour of the animals. The pink pigments of *Blepherisma undulans* is toxic to other ciliates.

ORGANELLES IN PROTOZOA

A. **VACUOLES.** Several kinds of vacuoles occur in different protozoa.

1. **Contractile vacuoles.** Contractile vacuoles are specialised vacuoles characteristic of *Ciliates*, *Flagellates* and *Sarcodina* but they are absent in Sporozoa. The position, number and accessory structures of the contractile vacuoles are different in different Protozoa (Fig. 9.48). The position of the vacuole in *Amoeba* changes with the movement of the organism. In forms with relatively fixed shape, i.e. *Flagellates* and *Ciliates*, the position is more or less fixed. In many *Heliozoans* contractile vacuoles occur in the ectoplasm. Deep-seated contractile vacuoles are often provided with a delicate duct which connects the vacuole with the pore on the pellicle as in *Paramoecium woodruffi.* In *Balantidium* and *Nyctotherus* the contractile vacuole is situated close to the cytopyge. The contractile vacuoles are generally spherical in shape but in many ciliates they have become star-shaped because of a number of collecting canals which radiate from the main vacuole. All the contractile vacuoles pass through a cycle. The origin of a new vacuole involves the fusion of many small vacuoles in the cytoplasm. The young vacuoles grow in volume (diastole) by fusion of other small vacuoles or by receiving contribution of fluids from visible canals. When the volume reaches its maximum the contents are discharged to the outside (systole) through the pores in the pellicle or into the gullet.

All fresh water protozoa solve the constant osmotic problem with the help of the contractile vacuoles. The plasmalemma in these organisms is semipermeable. And as the concentration of water in the cytoplasm is lower than that of the surrounding medium a constant flow of water into the animal body occurs. Water passes more rapidly into the body than it leaves. The organisms get rid of these excess water by pumping them out with the help of contractile vacuoles and prevent the body from being waterlogged. Thus osmoregulation is the sole function of the contractile vacuole. However, some amount of nitrogenous wastes are also voided along with the discharged water.

2. **Food vacuoles.** They are temporary vacuoles and are universally present in holozoic Protozoan which take in whole or parts of other organism. In forms which do not have a cytostome the food vacuoles assume the shape of the food. The food vacuoles are spherical in forms with cytostome. A number of food vacuoles may remain present at a time and they contain food particles at different stages of digestion. Food vacuoles in ciliates show a circulatory movement or cyclosis within the endoplasm. Food vacuoles are absent in saprozoic protozoan.

3. **Sensory vacuoles or Concretion vacuoles.** Certain parasitic ciliates of the families Butschliidae and Paraisotrichidae have a number of vacuoles located in the anterior region of the body under a pellicular cap. The vacuolar cavity contains a number of granules called *statoliths* and a number of fibrils join the vacuole with the pellicle. These vacuoles are considered as statocysts and excretory vacuoles.

4. **Superficial vacuoles.** Superficial vacuoles are found in passively floating Sarcodina which have a foamy outer cytoplasm. These thin-walled vacuoles presumably containing a light weight fluid or gas maintain the organism at a particular depth. When the vacuoles collapse the animal sinks. When new vacuoles develop the organism rises. Thus the superficial vacuoles help in floatation.

B. MOUTH AND ASSOCIATED ORGANELLE. Amoeboid organisms feed on bacteria or other small organisms and the ingestion of the food particle involves the formation of a food-cup to enclose the

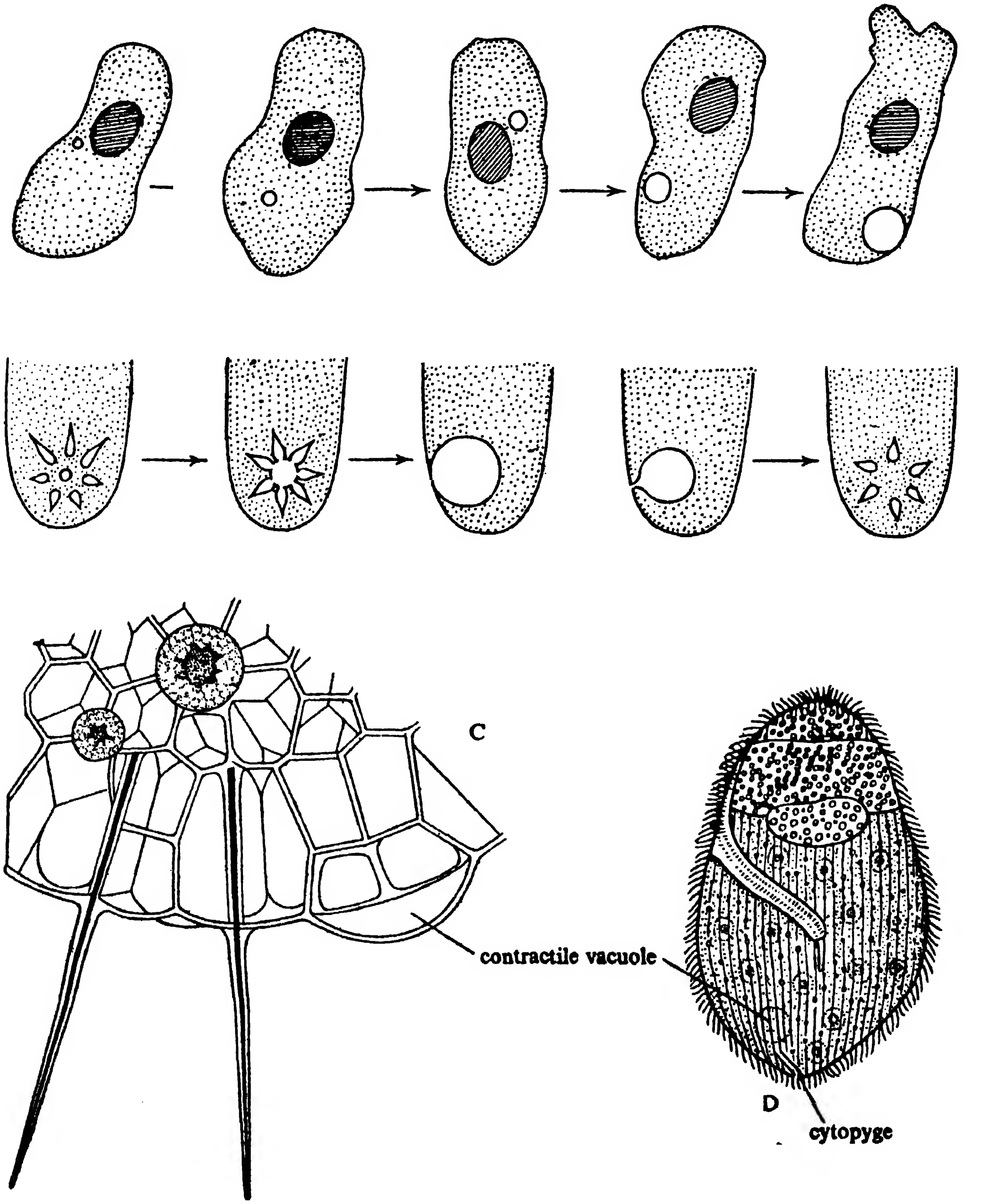


Fig. 9.48. Contractile vacuoles in some protozoa (after Weisz). A. Formation of contractile vacuole in *Amoeba*. B. Cycle of contractile vacuole formation in a ciliate (cilia omitted). C. Contractile vacuole in the ectoplasm of *Actinosphaerium*. D. Contractile vacuole in *Nyctotherus* is placed near the cytopyge.

prey or the formation of a gullet-like structure. In few phagotrophic ciliates and flagellates a gullet is formed during ingestion and persists during the active life of the organisms. Certain euglenoid flagellates possess an accessory rod-like apparatus which helps in puncturing the body wall of the host too large to engulf whole. Both the food cup and gullet are extra-temporary structures.

Permanent and specialised feeding organelles called cytostome is encountered in ciliates like *Paramoecium* and *Tetrahymena* (Fig. 9.49A). In *Tetrahymena*. there are three membranelles in the roof of the mouth and a membrane along the left margin. A membranella is composed of a double ciliary lamella fused to form plate. The membrane is thin, transparent and bears one or two rows of cilia fused together. The membrane is larger in *Tetrahymena* compared to other ciliates. In Hypotrichias the membranelles are very well developed but the membrane is ill developed. In ciliates the different stages of specialisation of the cytopharynx from an humble beginning to a complex end are readily recognisable.

In suctorians the tentacles play the role of the gullet. They feed on other ciliates which sometimes include an organism many times larger than itself (Fig. 9.49B). The tentacles adhere round the prey and it can hold an organism many times larger than it. Soon after adhesion the protoplasm of the captured ciliate starts flowing round the tentacle to the base where a food vacuole develops. The lining of the Suctorian tentacle is contractile and there is some sort of peristaltic action.

C. **CYTOPYGE OR CELL ANUS.** The indigestible residue of food in case of the ciliates is thrown out through a particular spot called cytopyge or cell anus. It lies at the posterior ventral side of the body. The spot is recognisable when excrement is actually being cast away. This is again a temporary structure. In *Nyctotherus* a permanent cytopyge is seen.

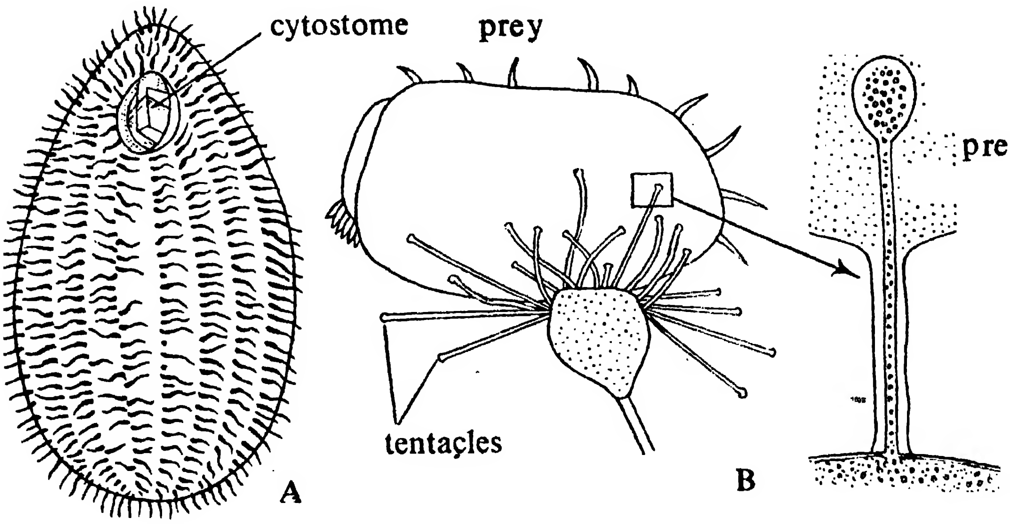


Fig. 9.49 Mouth and associated organelles in two protozoa. A. *Tetrahymena*. Note that cytostome is present near the anterior end of the body and along its same axis (after Kudo). B. *Left* shows a suctoria capturing its prey with tentacles. *Right* enlarged view of an extended tentacle of a suctoria in action (after Hall).

D. **LOCOMOTOR ORGANELLES.** Excepting a few Suctorians which are sessile in adult stage most protozoa possess definite locomotor organelles which are closely associated with the body surface. These organelles are:

1. **Pseudopodia.** These are characteristic organelles of Sarcodina, certain Sporozoa and many Mastigophore where the pellicle is ill defined. A pseudopodium may be defined as a temporary projection of a part of cytoplasm. According to form

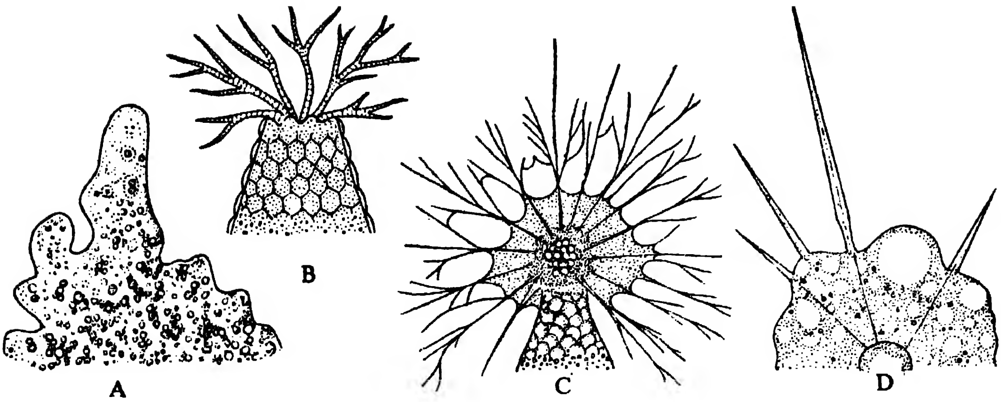


Fig. 9.50. Different types of pseudopodia. A. Lobopodia of *Amoeba*. B. Filopodia of *Euglypha*. C. Rhizopodia of *Chlamydophrys*. D. Axopodia of *Actinophrys*.

and structure four different kinds of pseudopodia are recognised. (Fig. 9.50).

(*a*) **Lobopodium.** Finger or tongue-like projection or projections accompanied by a flow of endoplasm and ectoplasm and the distal tip is always round. Both the formation and retraction of the pseudopodium are quick. One or more lobopodia may be formed at a time. *Amoeba proteus* throws lobopodium.

(*b*) **Filopodium.** Filamentous projections are formed by the ectoplasm alone. The filaments may be branched but do not anastomose. Filopodium is characteristic of the Testacians.

(*c*) **Rhizopodium.** Similar in structure to that of filopodium but the branches anastomose. It is found in foraminifera, e.g., *Elphidium*. The numerous branched and anastomosed rhizopodia form a network and help in capturing the prey.

(*d*) **Axopodium.** It is a semi-permanent structure and is made up of an axial rod enveloped by cytoplasm. The axial rod is made up of a number of fibrils and arises either from the central part of the body or from the nucleus or nuclei in multinucleate forms or from an intermediate zone between ectoplasm and endoplasm. Axopodia are found in *Actinophrys*, *Actinosphaerium*, etc.

2. **Flagella.** They are slender, filamentous extensions of the cytoplasm and are highly vibratile. A flagellum has got two components, an *axoneme* made up of several elastic fibrils and a *sheath* surrounding it. In some flagellates the axoneme is provided with lateral fibrils. A flagellum always originates from a blepharoplast or kinetosome embedded in the cytoplasm. In *Trypanosoma* and *Trichomonas* a delicate membrane called the undulating membrane extends out from one side of the body and a flagellum always borders the outer margin of the membrane. Generally there occur one or two flagella in an individual. Hypermastigina bear numerous flagella. Flagella bearing protozoa are the Mastigophora.

3. **Cilia.** The cilia are fine, short protoplasmic processes and emerge from

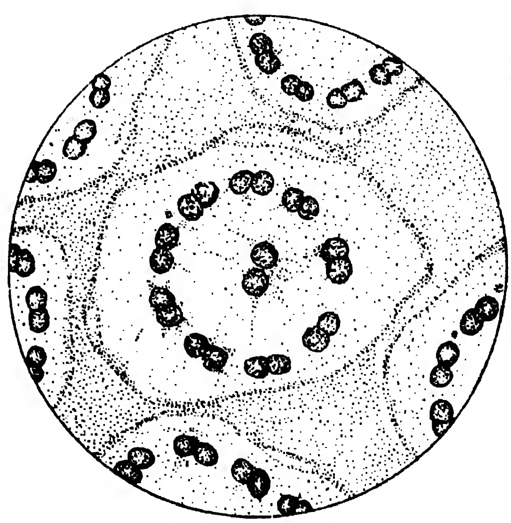


Fig. 9.51. Figure showing the sectional view of cilia as seen in electron micrograph. Note that a cilium is formed of nine '8'-shaped circularly arranged filaments and a similar cylindrical filament at the centre. A flagellum also has similar organisation (after Kimball).

the ectoplasm. Structurally they are identical with the flagella (Fig. 9.51). The cilia are arranged in longitudinal, oblique or spiral rows. The length of the cilia is uniform in Protociliates but in many ciliates the length is larger in certain parts of the body—namely the extremities and circumoral areas. Some parts of the body in some cases bear a dense population of cilia and these parts are called ciliary zones. In *Euciliates* the cilia fuse and form a membranella around the cytostome. In Hypotricha a number of cilia arranged in 2 to 3 rows fuse together and form a cirrus. Stiff and immobile cilia in between vibratile cilia occur in Stentor. The tentacles of adult Suctorians are considered as modified cilia. The myonemes are banded fibrillar structures and are striated.

E. CHROMATOPHORES, PYRENOIDS AND STIGMA. Chromatophores, i.e. chloroplastid and some non-green organelles are restricted to plant-like flagellates. The chromatophores occur in discoid, ovoid, band-like, rod-like or cup-like forms. In *Chlamydomonas* a single cup-shaped chromatophore is found and it is considered as a primitive form. This cup may be subdivided into pairs of lateral lobes or even to separate lobes. Some of the Euglenidae contain many flattened chromatophores arranged near the surface of the body. In *Peridinium* chromatophores are arranged near the surface of the body and form anastomosing network. Electron micrograph studies have revealed that chromatophores are double membranes and have a lamellar structure in which electron opaque layers alternate with electron transparent layers. Electron opaque layers are believed to be laden with photosynthetic pigments. Chlorophyll is the most predominant pigment in the chromatophores but there are other pigments present in significant amounts. These pigments are greenish yellow, yellow, red, brown and even blue and when present in superabundance they mask the green chlorophyll. The cytoplasmic pink pigment of *Blepherisma* is toxic to several other ciliates and to small metazoons. Even the annelid worm, *Dero* is susceptible to it. When exposed to very bright light, *Blepherisma* falls a victim of its own pigment or a toxic product of the pigment.

Pyrenoids are structures which usually remain associated with the chromatophores though all chromatophores bearing flagellates do not possess them. The structure of the pyrenoids varies from solid bodies to aggregate of granules. In *Euglena* the pyrenoid is encased in a layer of paramylum while in *Chlamydomonas* it is often surrounded by starch granules. From this close structural relationship it is suggested that pyrenoids are functionally involved in the synthesis of starch and other polysaccharides. However, there must be other machinery for the synthesis of these substances as there are certain flagellates without pyrenoid, which can synthesise such polysaccharides.

Stigma or eye-spot occurs in many chlorophyll bearing and a few colourless flagellates. The stigma contains reddish pigments presumed to be carotenoid. The stigma of Euglena shows a mass of reddish granules embedded in a matrix. It is a discoid body, placed close to the gullet. The flagellum which arises from the base of the reservoir through the gullet bears a small granule or a paraflagellar body at the level of the stigma. In *Volvox* and related colonial types the stigma is made up of a concave mass of pigments and a hyaline lens. The role of the stigma is to help in the orientation of the flagellates towards a suitable light source. From the work on *Euglena* it is assumed that the parabasal body of the flagellum is a light sensitive structure and it becomes stimulated by the light energy which the stigma absorbs.

F. NEUROMOTOR ORGANELLE. A well-defined system of nerves is lacking in the protozoon. But it has been seen that the cilia of the ciliates are capable of making a well co-ordinated movement. It is known that the ciliary co-ordination is due to the presence of certain fibrillar system in *Epidinium*. The presence of a neuromotor apparatus in the system of *Epidinium* is advocated. This apparatus consists of a central motor mass called the *Motorium* located in the ectoplasm and from it definite strands radiate to the roots of the membranellae, cytopharynx and other structures. Similar apparatus has been observed in *Balantidium*, *Paramoecium* and many other ciliates. Klein (1926) by silver-impregnation method has demonstrated the presence of such radiating fibrils and has designated the fibres as silver

lines and the whole complex as silver line system.

G. PROTECTIVE OR SUPPORTING ORGANELLES.

1. **Pellicle.** Outside the plasma membrane many protozoa have a differentiated pellicle, i.e., a continuous covering which may be more or less flexible. The thick pellicles often show surface decorations in the form of ridges, papillae or pits. The pellicle in ciliates is perforated through which cilia and trichocysts emerge. The chief component of pellicle in case of *Amoeba* is polysaccharide and in *Euglena* the principal component is protein.

2. **Exoskeleton.** Instead of a pellicle or in addition to a pellicle there occurs a covering which is exoskeletal in nature. These coverings are made up of inorganic materials in many flagellates and *Sarcodina.* In testate Sarcodina the covering is made up of siliceous plates. The theca of *Dinoflagellates* is a close fitting one while the test and the lorica are loose fitting ones.

3. **Central capsule.** The central capsule of the Radiolarians contains the nucleus or the nuclei and is a specialised chamber where reproductive processes go on. This capsule is considered as a protective organelle.

4. **Endoskeletal plates.** In many ciliates belonging to the family of Ophryoscolecidae which reside as commensals in the stomach of ruminants, the presence of a conspicuous endoskeletal plate is encountered. These plates arise from the oral region and run to the posterior region and are made up of hemicellulose or prismatic blocks of paraglycogen.

5. **Axostyle and parabasal apparatus.** It is a flexible rod-like structure running through the whole length of the body. Many Polymastigina and Hypermastigina bear axostyle. It is believed to perform a supportive function. Parabasal apparatus is a small or a long body coiled around the axostyle and its function is unknown.

6. **Costa and Cresta.** In Trichomonad flagellates a delicate filamentous structure extending from the blepharoplast to the base of the undulating membrane is seen. It acts as a support to the undulating membrane. Cresta is a triangular membrane that extends posteriorly from its anchorage near the nucleus and is of unknown function.

7. **Oral basket.** In many *Gymnostomalous* ciliates the cytopharyngeal wall is lined by a number of rod-like structures. These rods form a sort of basket and are considered as protective structures.

8. **Trichocysts.** These unique organelle are seen only in Holotrichs. The trichocysts are pyriform, fusiform or cylindrical in appearance and are embedded in the ectoplasm. They remain arranged at right angles to the body surface or in an oblique fashion. A trichocyst is made up of two parts—the tip and shank and the main body. The tip is straight, curved or bent and is connected with the pellicle.

The tip is provided with a cap. The main body is a straight rod which gradually tapers into a sharp point at the end opposite to the tip. The size of the trichocysts ranges from 20–40μ in length. Electron micrography has revealed cross-striations in the shank and a highly retractile granule at the base of the tip. Speculations run wide about the specific role of the trichocysts. They are considered as defensive organelle in *Paramoecium.* They serve as offensive organelle and help Didinium in capturing food. Some consider them as organelle for attachment while others believe that trichocysts secrete salts of sodium, potassium and calcium and are osmoregulatory in nature. Even they are considered as secretory organelles which produce materials for the development of lorica.

PHYSIOLOGY

There are many minute parts or organelle within the body of protozoa. These parts maintain the physiological activities in the cell body of the protozoa. It is difficult to get a thorough insight into the physiological problems of protozoa, and Calkins (1933) has very aptly stated, "Physiological problems of protozoa begin where similar problems of the Metazoa leave off, namely the ultimate processes of the single cell". However, information on various physiological activities of protozoa are under an accelerated progress through experimental researches.

NUTRITION. Nutrition in Protozoa is manifested by following ways:

(A) HOLOZOIC OR ZOOTROPHIC OR HETEROTROPHIC. In this method animals and plants smaller than the body of the protozoa are used as food sources (Fig. 9.52). The method is ultimately associated with ingestion, digestion, assimilation and egestion.

I. **Ingestion.** Most Sarcodina capture their food and take them inside the body through any part of the body. In Mastigophora and Ciliates food enters into the body through the cytostome. The lashing of flagella or cilia aids in bringing about the food particles to the cytostome. Food-getting is no problem to parasitic forms when they are inside the body of the host.

In Sarcodina the following methods have been observed for the ingestion of food particles:

(*a*) **Import.** The food is taken inside the body upon contact with little or no movement of body parts.

(*b*) **Circumfluence.** The food is surrounded on all sides by the cytoplasm and is engulfed.

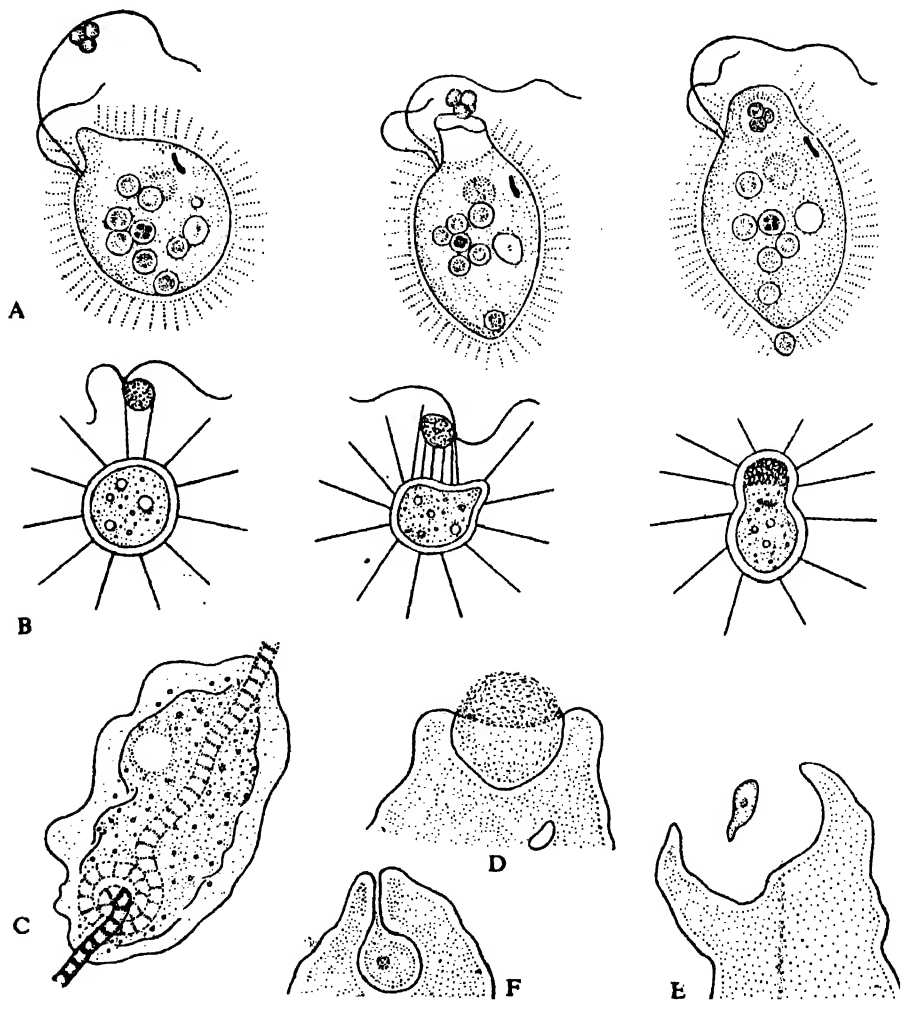


Fig. 9.52. Food capturing manouvres in certain protozoa.

A. Mechanism of food getting in the flagellate *Monas* sp. (after Hyman). B. Acts of food getting in a Heliozoan (after Hyman). C. *Amoeba* feeding in algae by the process-import (after Kudo). D. Feeding by circumfluence in *Amoeba* (after Kudo). E. *Amoeba* capturing food by circumvallation. F. Process of ingestion by invagination in *Amoeba*.

(*c*) **Circumvallation.** The amoeba forms

pseudopodia round the food particle and ingests it.

(*d*) **Invagination.** The ectoplasm of the amoeba, when comes in contact with the food particle, is invaginated or inpushed into the endoplasm as a tube. The cell membrane at the point of contact dissolves. Certain parasitic amoebae are capable of ingesting by invagination.

In certain ciliates like *Coleps* and *Didinium* the cytostome remains closed ordinarily but it expands to an enormous size during feeding and the whole food is ingested *in toto*.

In suctorians the tentacles are prehensile and solid or liquid food matter is sucked in through the tubular tentacles.

II. Digestion. The ingested food particles surrounded by a film of fluid remain in the endoplasm in 'food vacuoles'. The food vacuoles always remain in motion in the endoplasm and show 'cyclosis'. The vacuole contains food particles in killed, paralysed or alive conditions. However, all activities on the part of the prey stop a few minutes after its entry into the food vacuole. Digestion is done within the food vacuoles.

Observations of the changes within the food vacuole of amoeba are (*a*) the fluid inside the vacuole first becomes acidic and then alkaline. (*b*) Cytoplasmic secretions do not bring about the increased acidity inside the vacuole. Probably respiration of the ingested organism and chemical changes associated with the death of the organism are responsible for the change in pH. (*c*) Oxygen inside the vacuole decreases as it is being used up in the respiration of the organism inside the vacuole. (*d*) Decrease in oxygen results in the death of the captured prey. The existence of some 'lethal agent' inside the vacuole is also advocated.

Specific information about the processes involved in digesting the food particles is wanting and nothing is known about the localisation or distribution of enzymes within protozoan body. However, the findings made so far have indicated that the digestion in Protozoa is carried on by enzymes. The existence of enzymes like peptidase, proteinase, amylase, lipase, succinic dehydrogenase and others in different protozoa has been demonstrated.

Recent findings have established the existence of enzymes like acid phosphatase and esterase in *Amoeba proteus*. In recent years it has been advocated that protozoan cells contain elaborate set of hydrolytic enzymes and these enzymes participate in digestion. Some of these enzymes have been demonstrated as components of food vacuoles while others are secreted by the cell body into the surrounding medium. These hydrolytic enzymes have been divided into two functional groups—one group remains engaged in the digestive processes occurring within the cell either in food vacuoles or in the cytoplasm, while the other group releases enzymes in the surrounding medium.

III. Egestion. Non-digested residue is thrown out of the body through the plasma membrane or through cytopyge or temporary cell-anus.

(B) HOLOTROPHIC OR AUTOTROPHIC OR PHYTOTROPHIC. This type of nutrition is equivalent to the photosynthesis of plants. The process involves the photolytic decomposition of H_2O ultimately liberating O_2 and reduction of CO_2 to form carbohydrates. Holophytic nutrition is predominant in Phytomastigina and few chlorophyll-bearing ciliates. Recent studies have shown that some species of photosynthetic Euglenae when kept in the dark place for some days or are grown in media rich in certain organic nutrients lose their chlorophyll and tend to resemble the member of the genus *Astasia*. Moreover, treatment of Euglena with Streptomycin at a higher than standard temperature produces irreversible loss of chlorophyll. Such experiments indicate that some colourless genera of Euglenoids like *Astasia* might have been derived secondarily from photosynthetic species.

(C) SAPROZOIC OR SAPROPHYTIC. In this process the nourishing substances enter into the body by diffusion through body surface and no organelle is involved. The nourishing substances are simpler compounds formed by the activities of bacteria on dead or decomposed bodies of animals or plants. Many free-living protozoans, specially the flagellates, nourish themselves by this process.

(D) PARASITIC. Many protozoa live inside the body of other living organism and nourish themselves from the food

of the host. In some cases the digested or decomposed substances of the hosts enter into the body of the parasites by diffusion as in *Monocystis*. However, many parasitic protozoa like *Entamoeba* practice holozoic nutrition.

(E) MYXOTROPHIC. Flagellates like *Euglena* can nourish themselves in more than one method. On the demand of the external condition (in the absence of light) they can change their mode of nutrition from holophytic to saprophytic type.

RESPIRATION. Protozoa do not have any organellae for the process of respiration. The limiting permeable membrane acts as a respiratory surface. The free molecular oxygen from the surrounding media enters into the body by diffusion. Presence of a cytochrome system has been demonstrated in protozoa. Protozoa which live as parasites in the digestive tube of higher animals do not get molecular oxygen in free state but get it by decomposing complex oxygen bearing substances present in the body of the host. Anaerobic protozoa include *Trypanosoma gambiense* of vertebrate blood. While *Histomonas meleagridis*, a flagellate in the intestine of chicken can grow in presence of air as well as without it and is a 'facultative aerobe'.

EXCRETION. Waste products are water, carbon dioxide and nitrogenous compounds and remain in soluble forms. Waste materials are passed out of the body by diffusion or by the contractile vacuoles. Surrounding water is hypertonic to fresh water amoeba. So, water constantly enters inside the body of amoeba through the cell surface. This excess water interferes with the body functions and is eliminated by the discharge of contractile vacuole. Marine or parasitic protozoa live in isotonic media and do not have contractile vacuoles.

Some amount of carbon dioxide is diffused out through the cell surface. Rest of the carbon dioxide and ammonia which remain in soluble state are thrown out of the body by the contractile vacuoles.

Insoluble substances in the form of crystals of calcium phosphate (recorded in *Amoeba proteus*) ureate, carbonate, oxalate and grains (haemozomin in haemosporidians) are often encountered. These substances are considered as catabolic products. The way they are extruded is still in observation stage. In most protozoa excretion of nitrogen occurs in the form of Ammonia and free amino acid.

LOCOMOTION. Locomotion in protozoa is effected by three different ways. They are *amoeboid movement*, movement with the help of *undulipods* (i.e. cilia and flagella) and *gliding*.

1. **Amoeboid movement.** This is a most primitive kind of movement which is caused by contractility. Progression of the animal is made by throwing *pseudopodium* (Fig. 9.53). This type of movement is characteristic of Sarcodina and many Sporozoa.

In amoeboid progression, pseudopodia are formed in two different ways, *profluent* and *eruptive*. In profluent type, the ectoplasm bulges out as a blunt projection and endoplasm flows into this projection in an even manner. By profluent method a single pseudopodium (Limax) or many pseudopodia (Lobose) may be formed at a time. In eruptive type the ectoplasm and endoplasm burst out in an eruptive manner by dissolving the cell surface. Eruptive type of pseudopodium is restricted to small forms of amoeba where the gelated ectoplasm layer is very thin. The physiological manifestations in pseudopodia formation are explained with the help of **surface tension theory** and **change of viscosity theory.** In surface tension theory it is assumed that protoplasm is a fluid and as it is a fluid it must have a tension at its surface to make the mass spherical. Whenever the tension is lowered by external or internal changes, an outflow occurs and the fluid flows forward at the centre and back along the sides. The whole phenomenon is comparable to 'fountain streaming'. As surface tension theory cannot creditably account for the formation of pseudopodia in most amoeboid forms where the ectoplasm is gelatinised, a second theory, the change of viscosity theory, has been pronounced. This theory assumes that the cytoplasm in amoeba consists of an outer plasmagel and an inner plasmasol and the sol-gel state is reversible. A local reversion of plasmagel to plasmasol by internal chemical reaction causes an outflow at that point. As the outflow progresses, its side becomes gelatinised again and ultimately a pseudopodium made up of a gelatinised tube having

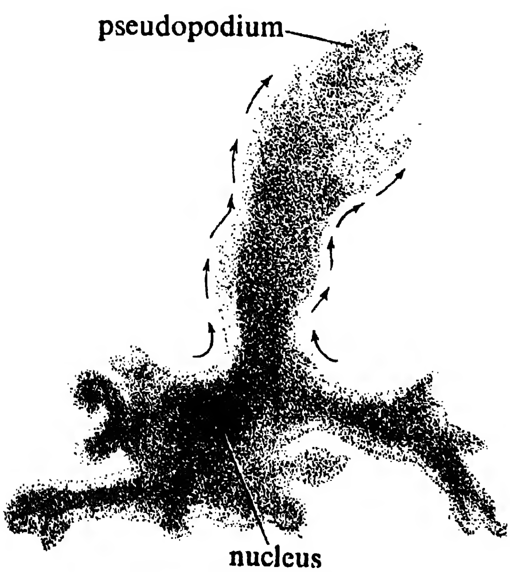


Fig. 9.53. A dynamic moment of pseudopodia formation in *Amoeba proteus* (Photography by courtesy of Dr. S. Mookerjce).

fluid inside and at the tip is formed. Mast (1931) has explained the phenomenon by stating that amoeboid movement is brought about by four primary processes, namely, attachment to the substratum, gelation of the plasmasol at the anterior end, solation of plasmagel at the posterior end and contraction of the plasmagel at the posterior end (Fig. 9.16).

2. **Flagellar movement.** The mechanism of flagellar movement (Fig. 9.54A-D) is not clearly known. As to the way in which a flagellum accomplishes locomotion there are three theories.

(*a*) **Screw theory of Butschli.** It postulates a spiral turning of the flagellum like a screw resulting a propeller action which pulls the animal forward.

(*b*) **Metzner's theory.** Metzner has advocated that the flagellum beats in a circle

tracing a cone and generates sufficient current to pull the animal forward.

(*c*) **Theory of Ulehla and Krijsman.** According to this theory the ordinary movement of a flagellum is a sidewise lash consisting of an effective downward stroke followed by a relaxed recovery stroke by which the flagellum is brought forward again.

3. **Ciliary movement.** All free swimming ciliates swim in a spiral path. During swimming an individual cilium bends throughout its length and strikes the water (Fig. 9.54E). As a result the organism moves in a direction opposite to that of the effective beat and the dispelled water moves in the direction of the beat. The cilia in the longitudinal row move metachronously (wave-like action) and those in the transverse row act synchronously (Fig. 9.54F).

4. **Gliding.** Parasitic protozoa which possess myonemes move by gliding, i.e. by contraction of the body and stalk. To aid the process mucous substances are sometimes secreted.

RESPONSE TO STIMULI. The reaction to stimulus in protozoa is expressed by movements. These movements may be classified in two broad groups; *Taxis* in which the reaction is directed towards the stimulus, i.e. positive reaction and *Kinesis* in which the stimulus increases the random movement of the animals and as a result the animals tend to move away from the source of the stimulus, i.e. negative reaction. Well-organised structures for the reception and conduction of a stimulus are lacking in protozoa. In amoeba, a stimulus is first received by the body surface and then by the whole protoplasmic body. The flagella or cilia, in flagellates and ciliates respectively are in part sensory. In ciliates there are certain cilia that are non-vibratile and appear to be sensory in function. Sensory organellae such as stigma, ocellus, statocysts and concretion vacuoles occur in many forms.

Response to mechanical stimuli. (1) An amoeba turns away, i.e. shows negative reaction when stimulated mechanically by the tip of a glass rod, (2) a suspended amoeba shows positive reaction when it comes in contact with a solid surface. The tip of the pseudopodium in such cases touches the surface and then adheres to it by spreading out, (3) positive

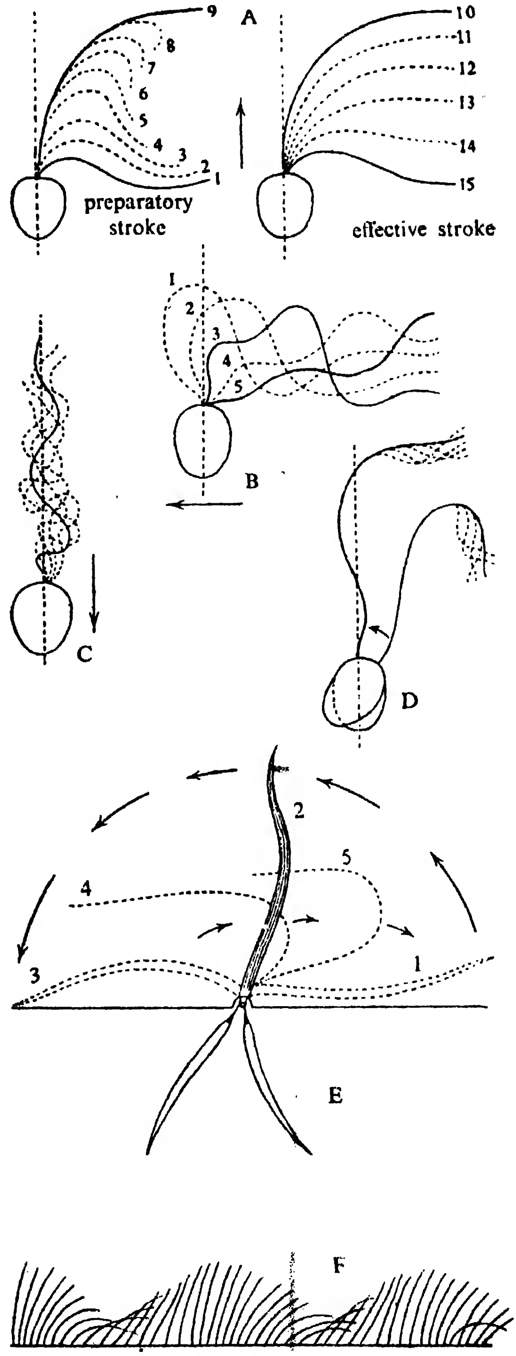


Fig. 9.54. Figure showing the types of flagellar and ciliary movement (after Kudo; Kimball).

A. Action of flagellum during forward movement. B. Flagellar action during lateral movement. C. Backward movement. D. Beating of flagellum during slight lateral movement. E. Action of a cilium. 1–3 effective strokes, 4–5 recovery strokes. F. Wave of ciliary movement in longitudinal axis.

reaction is shown by an amoeba during ingestion of solid food particle.

Response to chemical stimuli. An amoeba reacts negatively when it is brought in contact with salt solution, methyl green or methylene blue. Ciliates show positive reaction to acid solution up to certain concentration. In higher concentrations the reaction becomes negative. Chemotaxis is of great importance for the existence of protozoa since it helps them to find out the proper food. With the help of chemotaxis the parasitic protozoa find the specific site of their residence in the body of the host. Chemotaxis is believed to have a role in the process of sexual reproduction in protozoa.

Response to light stimuli. All protozoa are indifferent to an ordinary light source. Amoeba shows a negative reaction to strong light source while positive reaction to light is shown by stigma bearing mastigophora. Mastigophores in a jar concentrate at a place where the light intensity is maximum, if the jar is placed in a dark place the organisms remain scattered throughout the container, become inactive and encysted and myxotropic forms start practicing saprozoic method. Protozoa are sensitive to ultraviolet rays.

Response to electrical stimuli. Protozoa in water have been subjected to electric current and it has been observed that amoeba shows negative reaction to anode and moves towards cathode, free-swimming ciliates move to the cathode excepting *Paramoecium* and *Stentor* which move to the anode.

Response to temperature stimuli. There exists an optimum temperature range for each protozoan and it can withstand a little fluctuation of this range. In temperatures higher than the optimum, the metabolic activities of protozoa increase and reproduction, in quick succession, is followed. It is believed that temperature changes in the environment result in bringing forth different phases (trophic and cystic) in the life cycle of different amoebae.

Response to gravity. Reaction to the forces of gravitation is dependent upon body organisation and locomotor organelle. Bottom dwellers like *Testacea* show positive reaction to gravity while *Paramoecium* shows negative reaction.

Response to water current. Free-swimming forms orient themselves against the current. *Paramoecium* places itself in the line of current with anterior end upstream.

REPRODUCTION. Protozoans reproduce in a variety of ways and the process of reproduction is variable amongst different groups. But in all essence and purpose protozoan reproduction is nothing more than the division of the cell. It reproduces both *asexually* and *sexually*.

I. ASEXUAL REPRODUCTION. The following types of asexual reproduction are recognised in Protozoa:

A. Binary fission. It is the usual method in which the body of the individual divides into two equal halves and the furrow extends along the long and extended axis of the body. Binary fission may occur in a *transverse plane* as in *Paramoecium* and in a *longitudinal plane* as in *Euglena* and peritrichous ciliates. The different organellae present in the body may divide or they may be retained by one of the daughter cells, while the other cell regenerates the lost organelles. In extreme cases organelles disappear all together and are regenerated by both the offspring. Binary fission occurs in encysted condition in *Colpoda* and *Tellina* and in *Testaceans* one of the daughter individuals remains within the old test while the other moves away to form a new one.

B. Multiple fission or Sporulation. In multiple fission the body divides and a number of daughter individuals are formed. The nucleus divides a number of times and a multinucleate state results. The nuclei come to the periphery and gather some amount of cytoplasm round them. The cell-membrane breaks and daughter individuals corresponding to the number of nuclei are produced. The number of individuals produced by multiple fission varies and sometimes as many as 1000 individuals are formed. Multiple fission occurs in *Foraminifera*, *Radiolarians* and *Sporozoans*.

Multiple fission is also known by the following names:

1. **Schizogony or Agamogony.** When

the products of the fission directly develop into individuals as in *Plasmodium* in the red blood cells or hepatic cells of man.

2. **Gamogony.** When the products are sex cells as the *microgametocytes* of *Plasmodium.*

3. **Sporogony.** When it occurs following sexual fusion as in *Monocystis* and *Plasmodium.*

C. Plasmotomy. It is the division of the cell body without nuclear division and occurs in many multinucleate ciliates like *Opalina.*

D. Budding. It is a process in which one or more individuals are produced on the body of the parent and are budded off. The individuals generally do not resemble the mother and undergo further development before or after being free. Budding occurs only in *Suctoria.* The site of bud formation may be in or outer side of the body.

1. **Exogenous bud.** When the buds are constricted off to the exterior as in *Noctiluca* and some *Myxosporidia.*

2. **Endogenous bud.** When the buds are formed in the brood chamber or internal spaces of the mother body and come out later as in *Testaceans*, *Arcela*, Suctorians and many *Myxosporidia.*

E. Repeated fission. In which equal division of the nucleus occurs twice or thrice forming four or eight nuclei which do not separate till the process for which the nucleus divides is complete as in the micronucleus of *Paramoecium* and *Volvox.*

II. SEXUAL REPRODUCTION. In Protozoa the sexual reproduction occurs by the following processes:

A. Syngamy or Copulation. In which union of two sexual cells, called gametes occur. On the basis of structure and behaviour of the sexual units the following types of syngamy can be recognised:

(*a*) **Hologamy.** In which no true gamete formation takes place but two mature trophic individuals unite with each other and fusion of both nucleus and cytoplasm takes place. It occurs in few flagellates and rhizopods.

(*b*) **Isogamy.** The copulating sex units are similar in size and form and cannot be morphologically distinguished from each other though there exist physiological differences. The units are generally produced by multiple fission. Isogamy is common in Foraminifera, Gregarines and Phytomonadina like *Copromonas.*

(*c*) **Anisogamy.** It is fusion of dissimilar gametes. The copulating sex units are dissimilar in size, form and behaviour. The large and non-motile unit is called female or macrogamete and the small mobile one is termed male or microgamete in such fusion. They widely occur in Phytomonadina and Sporozoa, e.g. *Plasmodium.*

(*d*) **Autogamy.** When the copulating units originating from the same mother fuse—the phenomenon is called autogamy as in *Actinophrys.*

B. Conjugation. Conjugation may be defined as a temporary union of two individuals belonging to same species for the purpose of exchange of nuclear material. Conjugation is a complex process in which several nuclear divisions occur both in the preparatory and post-conjugation phases and one of these divisions is meiotic in nature. Conjugation occurs in Euciliates and Suctorians.

Aberrant reproduction in Paramoecium. Peculiar variation in behaviour of Paramoecium in nuclear division during conjugation is encountered. These variations in behaviour have been classified in the following ways:

(*a*) **Autogamy.** Very similar to conjugation but all the changes occur in a single individual. It is accompanied by fusion of pronuclei and meiosis and provides an opportunity for the reshuffling of genes. Autogamy occurs in *Paramoecium aurelia.*

(*b*) **Endomixis.** Similar to conjugation; but nuclear changes are restricted to a single individual. Fusion of pro-nuclei and meiosis does not occur though a new meganucleus is formed out of the micronuclear material as in conjugation. Endomixis occurs in *Paramoecium aurelia.*

(*c*) **Hemimixis.** The meganucleus behaves in a strange fashion. It divides into two or a part of it may be protruded into the cell mass. The meganuclear activity is independent of cell division or syngamy. It occurs in *Paramoecium aurelia*, *P. caudatum* and *P. multimicronucleatum.*

PARTHENOGENESIS. In case the syngamy is missed, gametes develop parthenogenetically. The examples are *Actinophrys*, *Polytoma* and *Chlamydomonas*.

REGENERATION. Protozoa possess a remarkable power to regenerate lost parts, provided nuclear material is included. When an amoeba is cut into two parts and the parts are kept in proper environment—the part without nucleus degenerates while the nuclear part regenerates. Shell of Foraminifera regenerates if broken. Besides these restorative regenerations in protozoa there occur regenerations of lost parts like cilia, flagella, cytostome and vacuoles after asexual and sexual reproduction. The process of morphogenesis in regeneration and reorganisation has been a subject of research.

NUCLEAR DIVISION

A. **Mitosis.** The modes of nuclear division during reproduction are worthy of consideration. Earlier the existence of mitotic phenomenon in protozoa used to be disregarded and it was advocated that in protozoa there occurs 'amitosis' or an unusual type of mitosis. Now it has been made evident that the nuclear division in protozoa passes through all the steps of mitosis and is identical with those of metazoan cells in most cases and in the rest they are abbreviated. The mitotic phenomenon in protozoa is described in the following ways:

(1) **Eumitosis.** When there is distinct chromosome formation and chromosomes on the whole behave like those of the metazoan. Eumitosis is a common feature of free-living forms.

(2) **Paramitosis.** The chromosomes during paramitotic division do not shorten at metaphase and remain asymmetrically arranged on the equator of the spindle. The sister chromatids do not lie side by side but hang together at one end. As a result during separation they present a picture of false transverse division of chromosomes.

Paramitosis occurs in Coccidians, Dinoflagellates, etc.

(3) **Cryptomitosis.** In cryptomitosis translation of the chromatin material into chromosomes is lacking and the whole chromatin material is lodged as a mass on the equator of the spindle. The chromatin mass becomes divided into two halves which go to the two poles.

Cryptomitosis occurs in parasitic and coprozoic forms like *Haplosporidium* and *Naegleria*.

B. **Meiosis.** The Protozoan nuclei undergo divisions prior to sexual reproduction. And it is expected that one of these divisions should be meiotic in nature so that the constancy of the number of chromosomes could be maintained. Information about meiosis in protozoa is scanty or fragmentary. Meiotic division in protozoa may occur before the formation of gametes (pre-gametic) or after the fusion of gametes (post-zygotic). Pre-gametic meiosis occurs in *Paramoecium* and post-zygotic in Telosporidia.

CYTOPLASMIC DIVISION

The division of nucleus is followed by division of cytoplasm and extranuclear organelles such as chromatophores and pyrenoid, blepharoplast and kinetosome. But nuclear division in encysted condition results accumulation of cytoplasm round each nucleus and there is no cytoplasmic division in true sense.

ENCYSTMENT

Many protozoa exhibit a phase reversal. At one phase of life cycle they remain active and carry on vital life processes and in another phase they become inactive and discard most of the life processes. The active phase is called *trophic* or *trophozoite* stage and the inactive phase is called *cyst* and *cystic* stage. That means many protozoa are capable of existing alternately as trophic and cystic forms.

During the transformation from trophic to cystic the trophozoites cease to ingest, extrude remains of food particle and become round in appearance. This phase is called the *pre-cystic* phase. De-differentiation of the whole organism now occurs and cell organellae like cilia, peristome, axostyle, contractile vacuole, etc., are absorbed. Finally, they secrete substances which solidify and form resistant walls round the organism. Thus a *cyst* is formed. The number of walls in a cyst varies from 1–3. The cysts are capable of remaining viable for a long time. The wall of the cysts contains siliceous plates in *Euglypha*,

cellulose in Phytomonadina and chitinous elements in most cases.

Low and high temperature, evaporation, change in pH, accumulation of metabolic products and even over population are the conditions which lead a protozoa to encyst. Cysts may be *protective* when it is formed in unfavourable conditions, it may be *reproductive* when fission occurs inside the cyst and it may be *digestive* when it is formed immediately after food intake and overfeeding. On encountering a suitable and proper environment excystment occurs. During excystment various organellae characteristics of the organism are re-differentiated and reformed. The trophozoite emerges through a pore on the cyst wall. Little is known about the specific mechanism by which an aperture is formed on the cyst wall. The rapture of the cyst wall may be caused by the following processes:

(*i*) Increase in the internal pressure by accumulation of water inside the cyst causes the rapture of the cyst wall which loses its rigidity and resistance.

(*ii*) Pseudopodial activity inside the cyst wall leads to the formation of aperture on the cyst wall.

(*iii*) Dobell has proposed that in *Entamoeba* secretion of an enzyme is responsible for the dissolution of the cyst wall.

Experimentally encystment can be induced by the addition of fresh culture medium, distilled water, organic infusions and by lowering the temperature or changing the pH.

The success and wide distribution of protozoa are probably due to its ability to encyst. The cysts are minute and are easily transported from one place to another by various agents such as wind, water current, soil particles, insects, birds and other animals.

Encystment is an essential and important phase of life in most protozoa though the presence of this phase has not been encountered in *Paramoecium* and *Amoeba proteus*.

WHY STUDY PROTOZOA? Study of Protozoa or Protozoology has a direct bearing on other branches of Zoology. Protozoa occur as single cell and provide excellent materials for the study of the nature and mechanism of cellular activity at unit level. Information accrued from such studies gives a thorough comprehension of biology and Biological principles.

Geneticists have focussed their attention on protozoa because the group "presents all problems of heredity and variation in miniature". The advantage of using protozoa as a genetic material is that it reproduces at a quicker rate and may offer a generation in a day for the study of variation and heredity. Study of conjugation in *Paramoecium* has revealed many interesting information about protozoa genetics and the interrelationship between nucleus and cytoplasm in attributing hereditary factors.

Many protozoa live as endoparasites in man and domestic animals and cause diseases. Studies of protozoon parasites thus become an imperative necessity for medical practitioners and veterinarians.

Study of a particular group of protozoa and their hosts helps in realising the geographical condition of the planet earth which existed in remote past. The genus *Zelleriella* is a parasitic protozoa in the colon of frog. *Zelleriella* studied from frogs of South America and Australia have been found to be identical. It is more logical to think that there existed a land connection between Patagonia and Australia through which migration of frogs containing *Zelleriella* occurred than to think that both the host and parasite have undergone parallel evolution in these two continents.

Parasitic protozoon remains confined to one or more specific hosts. A thorough study of the parasitic forms belonging to one and the same genus helps in establishing or verifying the phylogenetic relationship between the hosts. From the study of the termite protozoa it has been shown that Blattidae and Isoptera are closely related.

For a success in fish culture study of protozoa is essential. Small aquatic organisms as Crustaceans, Annelids and larvae of insects constitute the main bulk of food for the fishes and the organisms on the other hand thrive on protozoa. Thus the fishes are indirectly dependent upon protozoa and are related to it in the food chain. Myxosporidians are parasites on fishes and are responsible for large-scale fish death. Study of protozoa is thus a must in fishery.

Application of protozoa in the biocontrol of certain harmful insects is a

recent development. Microsporidians infect insect pests such as mosquito and Lepidoptera and heavy infection causes death. Destruction of these insects by pesticides sometimes fails as the insects develop an immunity to the pesticides. For the bio-control of pests attention has now been drawn on protozoa.

Fossil forms of shelled protozoa like Foraminifera and Radiolaria are used in the study of Geology and Palaeontology. Skeletons of Foraminifera occur in many rock strata and the foraminiferous rocks are useful in checking the logs during well-drilling. Skeletons of Radiolaria have formed many oozes of littoral and deep-sea regions and they are also found in silicious rocks. Study of the shells embedded in the rock strata helps in finding out the geological time scale and in petroleum prospecting.

SUMMARY

1. Phylum Protozoa is primitive and includes unicellular animals.
2. The single cell of Protozoa performs all the vital functions of life.
3. Protozoans are adapted to all sorts of environments available to micro-organisms.
4. The modes of life of Protozoa are free-living, parasitic, saprozoic or myxotrophic.
5. Excepting a few rhizopods all Protozoa have more or less a fixed shape.
6. Cell body of Protozoa consists of plasmalemma, cytoplasm and nucleus.
7. The shape, size and number of nucleus are variable. Generally they are uninuclear but multinuclear condition is also common. In many ciliates there exist a macronucleus and one or more micronuclei.
8. Cytoplasm is colourless, granulated, vacuolated or reticular in nature and is often differentiated into ectoplasm and endoplasm.
9. Cytoplasm includes stored food like polysaccharides and lipids. Mitochondria, Golgi apparatus and many pigments are also included.
10. The plasmalemma is a thin membrane and regulates the entry and exit of materials between the organism and environment.
11. Some members have close fitting shells.
12. Various organellae are included in the cell-body.
13. Contractile vacuoles help in osmo-regulation and excretion.
14. Food vacuoles help in housing the food and its digestion.
15. Ciliates among the Protozoa have a permanent mouth or cytostome.
16. Locomotor organellae are of various nature and are the sole criteria in classification.
17. Pseudopodia are locomotor organellae in Sarcodina.
18. Flagella and cilia are used in locomotion in Flagellates and Ciliates.
19. Definite structure for respiration is absent. The whole body surface is used in respiration.
20. Reproduction occurs in a variety of ways.
21. Binary fission is the usual mode of reproduction and it is asexual. Multiple fission is another mode.
22. Sexual reproduction also occurs.
23. Conjugation in Paramoecium is a complicated process.
24. Under unfavourable condition many possess the capacity to become encysted.
25. Study of Protozoa or Protozoology is important in many respects.

CHAPTER 10

Phylum Porifera

In the history of animal evolution, the sponges are regarded as the first step towards multicellularity. The animals belonging to this phylum are generally called the sponges. They possess specialised structures like canals, spicules, gemmules and many others. They had long been included under Coelenterata. Grant (1836) studied the sponges quite extensively and gave the name Porifera (L. *Porus*=pore and *ferro*=to bear) to the group (Fig. 10.1). The sponges are now given the independent status of a separate phylum. They have peculiar taxonomical status occupying a transitional phase between the Protozoa and other Metazoa. The sponges are distinct from the protozoans in having cellular grade of structural organisation and from other metazoans in lacking the tissue grade of construction.

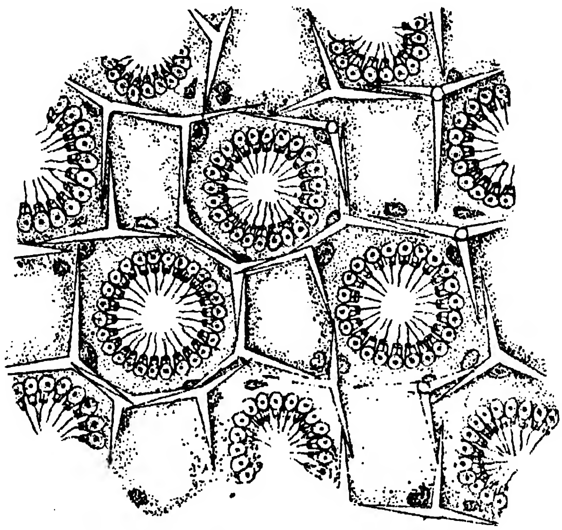


Fig. 10.1 Sectional view of a sponge. The body includes certain structures, i.e. pores, canals and spicules which are not seen in any other animal.

IMPORTANT FEATURES

1. The sponges are sessile in adults. They have asymmetrical or radially symmetrical bodies with cellular grade of construction. 2. The body is perforated by a number of pores, hence the name of the group is Porifera. 3. They possess peculiar canal system through which water current flows and conveys food and oxygen. 4. They possess one or many internal cavities lined by choanocytes. 5. They are without any organ system. 6. Nervous tissues are not formed. 7. In all the forms, one or more internal spaces with choanocyte lining, are present.

OUTLINE CLASSIFICATION

The phylum Porifera comprises of three classes—*Calcarea* or *Calcispongiae*, *Hexactinellida* or *Triaxonida* or *Hyalospongiae* and *Demospongiae*. There are about 5,000 described species.

Example of the Phylum Porifera—*LEUCOSOLENIA*

The structural organisation of sponges will be best understood from the study of some simpler forms like the genus, *Leucosolenia*. This simplest form of sponge represents the asconoid type. It has a symmetrical vase-like body. The wall of the body is comparatively thin. The inner side of the body wall is lined by flagellated cells or the *choanocytes* and the outer wall is called the *epidermis*. In between the epidermis and the choanocyte layer lies the *mesenchyme*. The mesenchyme has a gelatinous matrix containing spicules and different types of amoeboid cells. The body encloses a cavity called *spongocoel*. The spongocoel opens to the exterior by an

aperture at the summit called *osculum*. The wall of the body is pierced by a large number of minute openings called the *ostia*. Each ostium is intracellular in nature and opens through a large tubular cell known as *porocyte*. The ostia connect the inner spongocoel with the external body surface. Water rushes into the spongocoel through the ostia and goes out to the exterior through the osculum. The cell types and mode of life resemble the pattern of other sponges and will be discussed in detail with the description of another example of the phylum, i.e. *Sycon*.

Example of the Phylum Porifera—*SYCON* (*SCYPHA*)

Habit and Habitat. *Sycon* is a marine sponge and remains attached to solid substrata like rocks, shells of molluscs and corals. The name of genus, *Sycon* is replaced by *Scypha* by de Laubenfels (1936). But in our present discussion the name Sycon is retained. The different species of sponges under the genus do not tend to live at greater depths in the ocean.

Structure. The sponges exhibit a great diversity in form. They range from a very simple to more complicated forms. Sycon occupies an intermediate status from the point of structural diversities. It has the form of branched cylinders of about 2·5 to 7·6 cm. in length. All the branches are connected together at the base which remains attached to the substratum. Though the body has a firm consistency, it is slightly flexible. Close examination of the surface reveals the presence of innumerable minute *inhalant pores* or *ostia*. The free end of each cylindrical branch possesses an opening at the summit. This opening is known as *osculum* (Fig. 10.2).

Canal system. Sycon, like all other sponges, possesses the characteristic anatomical peculiarity—the *canal system*. It permeates the body with water channels. It plays a very important role in the life of Sycon. The particular type of canal system encountered in Sycon is known as the **Syncoid (Stage I) type** (Fig. 10.3) which is practically more advanced than the asconoid canal system.

If the cylindrical body of Sycon is bisected longitudinally, it is observed that the osculum leads into a narrow tubular cavity called the *paragastric cavity* or *gastral cavity* or *spongocoel*. Although this cavity is variously named, the name of spongocoel seems to be most appropriate.

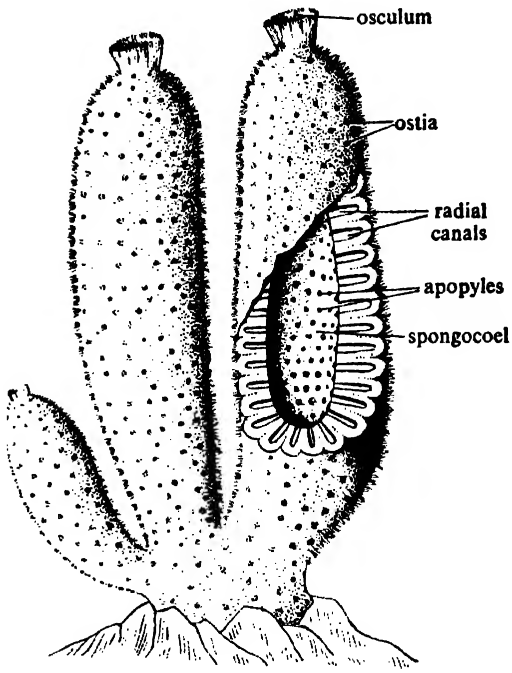


Fig. 10.2. External features of *Sycon gelatinosum*. A portion is excised to show inner organisation.

The body wall lining the spongocoel is outpushed at regular intervals as finger-like projections. These projections are called *radial canals*. The wall of the radial canal is lined with *choanocytes*. In between two successive radial canals, a tubular space called *incurrent canal* is present. Thus radial canals and incurrent canals are arranged alternately and the latter opens to the exterior through *ostia*. The wall between the incurrent and radial canals is pierced by numerous minute pores called *prosopyles*. In Sycon, each prosopyle is an intercellular space or channel while in Leucosolenia these pores are intracellular. The openings of the radial canals into the spongocoel are called *internal ostia* or *apopyles*. Finally the spongocoel opens to the exterior by *osculum*.

The circulation of water in Sycon takes place in the following way (Fig. 10.4). The course of water current has been studied by the application of fine carmine particles to the surface of the body. The water rushes inside the body through numerous ostia along the external surface. Each ostium or dermal pore leads into an

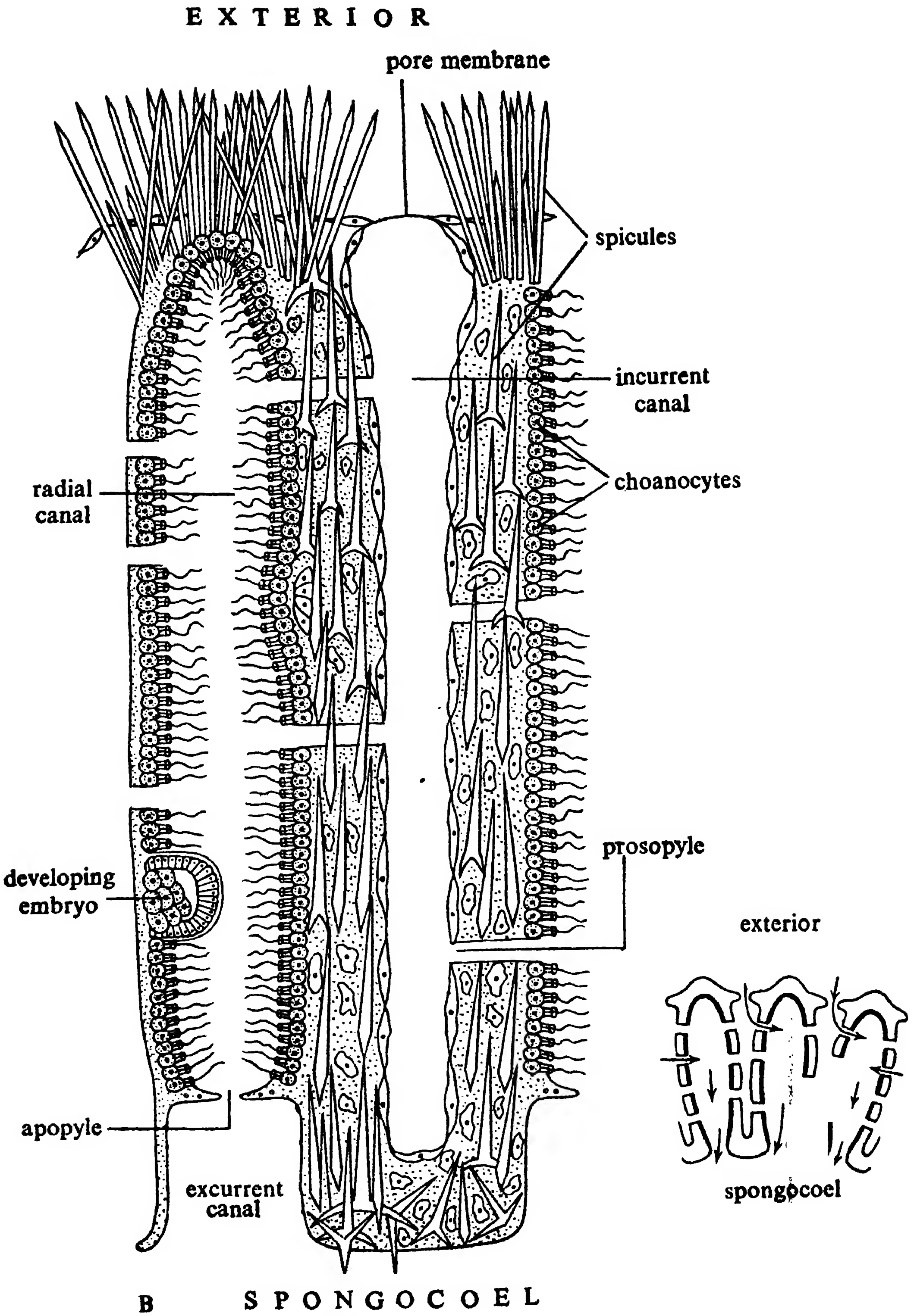


Fig. 10.3. Sectional view of *Sycon* (Diagrammatic). A. A portion of the body to illustrate the arrangement of canals. B. Part of 'A' is magnified to show the histological details (after Parker & Haswell).

incurrent canal. From the incurrent canal, the water flows inside the radial canal through prosopyle. From radial canal water passes out through apopyles into the spongocoel. The spongocoel is thus a common chamber within which all the radial canals of the body open. The

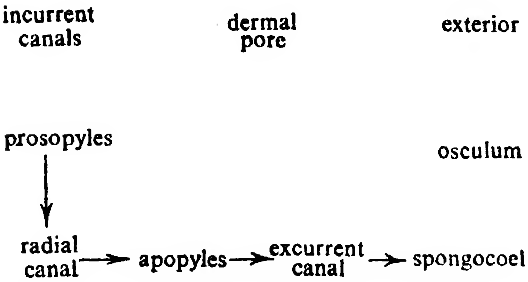


Fig. 10.4. Course of circulation of water in *Sycon*.

spongocoel ultimately opens to the exterior through an aperture, the osculum. Water enters inside the body through numerous doors (ostia) but passes out through a single opening (osculum). The synchronous beating of the flagella of choanocytes in the radial canals produces a current which in one hand draws the water inside and on the other hand forces it to go out.

Microscopic organisation. The microscopic organisation shows the presence of a single layer of cells covering the outer surface of the body. This outer layer is designated as the *dermal layer*. Needle-like *spicules* are seen to project from this layer. This layer is composed of large cells called the *pinacocytes*. The spongocoel is lined by a layer of flattened endodermal cells. Radial canals are lined by peculiar collar cells, each having a long whip-like flagellum. These cells are called the *choanocytes* or *collar cells* or *gastral cells*. Each choanocyte has a round or oval body. It possesses a nucleus and one or many vacuoles in its cytoplasm. The free end of the cell body has a comparatively longer flagellum and the base of the flagellum is surrounded by a contractile transparent collar-like outgrowth of the cytoplasm. Electron microscopic studies have revealed that the collar-like outgrowth is composed of cytoplasmic tentacles. The number of such tentacles is variable. The incurrent canals are lined by dermal cells.

The spicules, which constitute the skeleton of Sycon, develop from the *scleroblasts*. These structures are regularly arranged and protect the softer parts. Triradiate as well as tetraradiate spicules are common. Besides these, simple club-like *oxeote* spicules are also present.

The intermediate layer consists of gelatinous matrix with spicules and numerous amoeboid cells. Some of the amoeboid cells are large and their nuclei show distinct nucleoli. These cells are called *archaeocytes*, which are of different forms and sizes. Most of the other cells are smaller and stellate-shaped and possess radiating processes. These cell types are usually called the *collencytes* or *connective tissue cells*.

The osculum, prosopyles and apopyles have elongated narrow cells which prolong into narrow fibres around the aforesaid apertures and help them to close, when necessary.

Nutrition, Respiration and Excretion. The sponges feed on micro-organisms which enter into the body along with the water current. The choanocytes engulf them and pass them to the amoeboid cells situated below the choanocytes. The digestion takes place inside the amoeboid cells and assimilated products are conveyed to the various parts of the body. Thus nutrition is holozoic and digestion is intracellular, a process comparable to that of protozoans. Some amoeboid cells often contain chlorophyll or green pigments and carry out autotrophic nutrition like green plants. The presence of algae within the sponge body also helps in nutrition. Respiration and excretion take place by diffusion. The contractile vacuoles are recorded in the amoeboid cells of fresh-water sponges which probably play important role in osmo-regulation and excretion.

Reproduction. Sycon reproduces both *asexually* and *sexually*. During asexual reproduction it produces bud and sometimes produces special bodies resembling the *gemmules* of fresh-water sponges.

During sexual reproduction, both sperms and ova are produced from the archaeocytes which are present in the mesoglea. It is claimed that the sex cells are also produced from adult choanocytes. The sperm cells have long tails and swim freely in water current. The ova are amoeboid and wander through the mesoglea. The ova may grow up in size by ingesting other cells. The sperm cell does

not enter the ovum directly. The union is assisted by a choanocyte. When sperm cells enter the radial canal, the choanocyte which is nearer to the egg captures it. The choanocyte which absorbs the sperm discards its flagellum and collar and comes

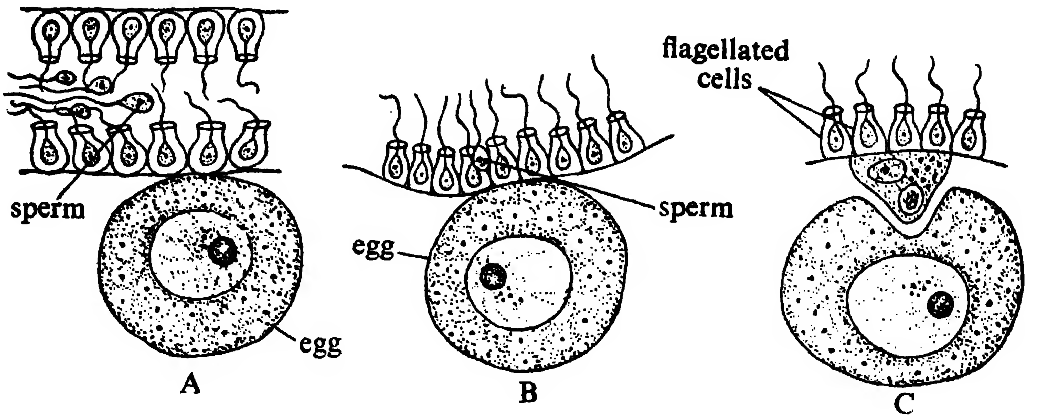


Fig. 10.5 Schematic representation of sexual reproduction in *Sycon*. A. Sperm cells enter with the water flow into the radial canal. The matured egg waits beneath the lining of the choanocytes. B. The choanocyte nearer to the egg engulfs the sperm. C. The sperm is then transferred to the egg for fertilisation.

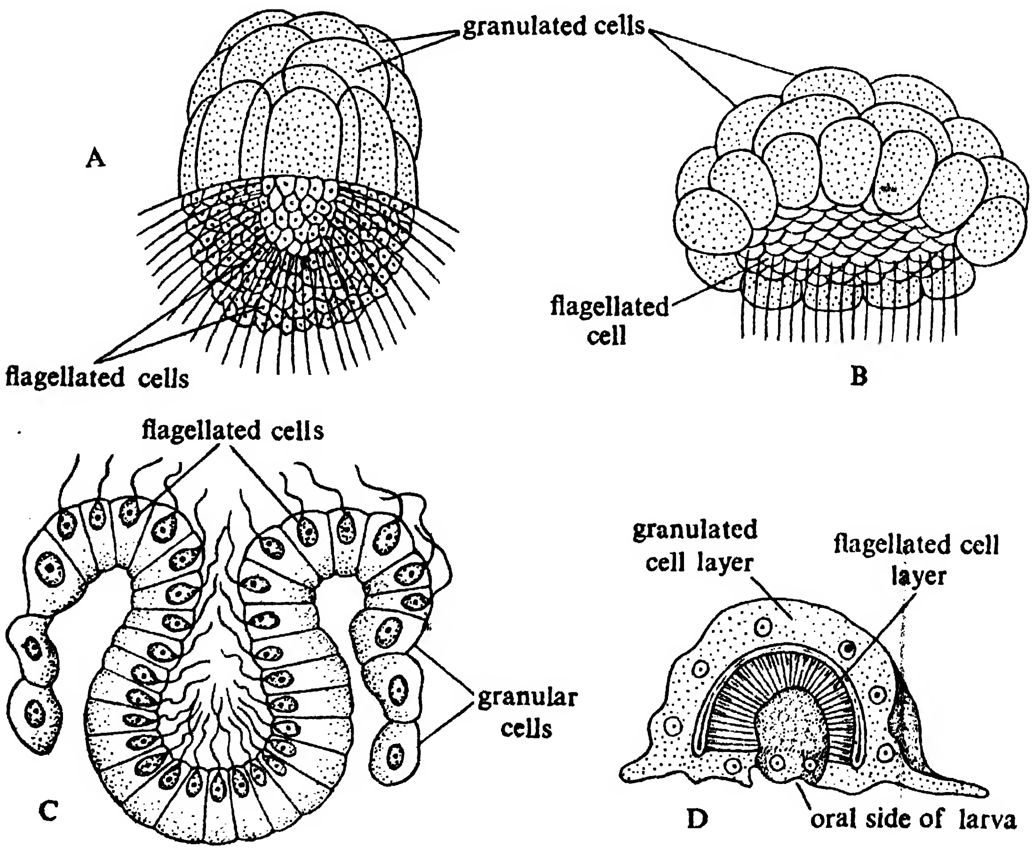


Fig. 10.6. Stages of development in *Sycon* (after Parker & Haswell).
A. Amphiblastula stage. B. Invaginating amphiblastula stage. Note that the flagellated cells are going to be tucked in. C. Sectional view of late amphiblastula showing the invagination of flagellated cells. D. Fixed stage of larva (sectioned to show internal disposition).

very near the egg. This choanocyte is named as the *carrier cell*. The sperm subsequently loses its tail and enters the egg. The carrier cell is ultimately absorbed. The early development takes place within the body of the mother sponge (Fig. 10.5). When the development is complete, the larva forces its way into the radial canal and finally to the exterior.

Development. The fertilized egg or zygote divides repeatedly to form a round mass of cells (Fig. 10.6). It is mostly covered with homogeneous cells but at one end a few thickly granulated cells appear. The homogeneous cells grow flagella and completely enclose the granulated cells. Soon the cells at one half lose their flagella and become large and granular. This stage is called *amphiblastula* stage and the larva in this stage leaves the parent body. Gradually the flagellated cells invaginate and finally the granular cells completely enclose the flagellated cells. The flagellated cells form the choanocyte lining while the granular cells give rise to the dermal epithelium. The larva fixes itself to a substratum and an aperture called osculum appears at the free end. Further growth results into the thickening of the wall within which flagellate cells traverse and thus leads to the formation of radial canals. Numerous pores appear on the sides to form inhalant apertures.

CLASSIFICATION

Opinions vary regarding the classification of sponges. The grouping is based primarily on the nature of spicules and such divisions are not unanimous particularly in the case of horny and siliceous sponges. The scheme of classification of the Phylum Porifera adopted in the present text is based on the classificatory plan outlined by L. H. Hyman in her book, "The Invertebrates: Protozoa through Ctenophora Vol. 1".

CLASSIFICATION IN OUTLINE

PHYLUM PORIFERA. The phylum is subdivided into three classes—*Calcarea*, *Hexactinellida* and *Demospongiae*.

1. CLASS **Calcarea** or **Calcispongiae**
   Order *Homocoela*, e.g. *Clathrina*, *Leucosolenia*
   Order *Heterocoela*, e.g. *Sycon* (*Scypha*).

II. CLASS **Hexactinellida** or **Triaxonida** or **Hyalospongiae**
   Order *Hexasterophora*, e.g. *Euplectella*
   Order *Amphidiscophora*, e.g. *Hyalonema*

III. CLASS **Demospongiae**
   A. *Subclass* Tetractinellida
      Order *Myxospongida*, e.g. *Oscarella*
      Order *Carnosa*, e.g. *Plakina*
      Order *Choristida*, e.g. *Ancorina*
   B. *Subclass* Monaxonida
      Order *Hadromerina*, e.g. *Poterion*, *Cliona*
      Order *Halichondrina*, e.g. *Halichondria*
      Order *Poecilosclerina*, e.g. *Microciona*
      Order *Haplosclerina* e.g. *Spongilla*
   C. *Subclass* Keratosa, e.g. *Euspongia*

CLASSIFICATION WITH CHARACTERS

Class **Calcarea** or **Calcispongiae**

The sponges included under this class have comparatively large collared cells and the skeleton is represented by free calcareous spicules. Such spicules contain more calcium carbonate than magnesium carbonate. For example, in *Leucandra* the spicules contain—$CaCO_3$ 87%, $MgCO_3$ 7%, Organic matters in traces. The sponges included under this class are comparatively smaller in size extending up to 10 cm. in height. Individualism is strongly marked. The osculum is narrow and placed terminally. The osculum is provided with *oscular fringe*.

The Class Calcarea contains two orders:

Order *Homocoela*. Typical examples of this order are *Clathrina*, *Leucosolenia*, *Ascute*, *Ascyssa* and *Dendya*. The choanocyte cells are present throughout the internal lining membrane.

Order *Heterocoela*. Typical example is *Sycon*. Only the radial canals are lined by choanocytes.

Class **Hexactinellida** or **Triaxonida** or **Hyalospongiae**

Triaxon siliceous spicules or their modifications are present either as separate entity or as networks. Choanocytes are restricted to finger-like simple or folded chambers. The wall encloses a spongocoel which opens by a wide osculum. It may be covered over by a sieve-like plate

of silica. The chemical analysis has revealed that (e.g. *Monoraphis*) the spicule contains SiO_2 86%, water 9%, inorganic elements 3%, spiculin (a protein) 2%.

Order *Hexasterophora*. The typical example is *Euplectella* where the spicules are hexasters and never amphidiscs.

Order *Amphidiscophora*. The example of this order is *Hyalonema*. The hexaster spicules are absent and the spicules are amphidiscs.

Class **Demospongiae**

This class includes the sponges which are either skeletonless or only spongin fibres are present or both spongin fibres and siliceous spicules are present. These siliceous spicules are never triaxon. The choanocytes form very small, round type of flagellated chambers.

Subclass Tetractinellida.

Sponges under this subclass are characterised by the possession of tetraxon spicules but the spongin fibres are absent. In certain forms the spicules may be absent.

Order *Myxospongida*. The typical representative is *Oscarella* where spicules are absent.

Order *Carnosa* or *Homosclerophora* or *Microsclerophora*.

The typical representative is *Plakina*. The megascleres and microscleres are not distinctly separable.

Order *Choristida*. The typical examples of this order are *Ancorina*, *Craniella*. Spicules are long-shafted. Megascleres and microscleres are distinctly differentiated.

Subclass Monaxonida

The sponges included under this subclass possess spicules of monaxonial megascleres. Spongin may or may not be present.

Order *Hadromerina* or *Astromonaxonellida*. Megascleres are mostly tylostyles, i.e. broad end is knobbed. Microscleres are usually wanting; when present, they are in the form of a star. Spongin is absent. *Tethya* and *Cliona* are typical examples.

Order *Halichondrina*. The example of the order is *Halichondria*. Megascleres are always of more than one kind. Microscleres are usually absent. Spongin is very scanty.

Order *Poecilosclerina*. The example of the order is *Microciona*. Megascleres are usually of two or more kinds and are localised. Microscleres include the C-shaped, curved and bow-shaped types.

Order *Haplosclerina*. *Haliclona* and *Spongilla* are typical examples. The megascleres are always diactinal, i.e. growth takes place at both directions and are not localised in distribution. Microscleres may or may not be present. Spongin is usually present.

Subclass Keratosa

The typical example of this subclass is *Euspongia*. The skeleton is exclusively composed of spongin fibres. The siliceous spicules are usually absent.

GENERAL NOTES ON SPONGES

HISTORY

The biological nature of sponges had been a debated issue until well into the 19th century. Up to the 18th century sponges were not considered as animals. Ellis in 1765 noticed the flow of water and contractile activity of osculum in sponges and established their animal nature.

Linnaeus, Lamarck and Cuvier considered them as related to anthozoan polyp and included sponges within Zoophytes or Polyps. Sponges were included under coelenterates up to nineteenth century though de Blainville (1816) proposed to separate sponges from coelenterates and created a group *Spongiaria* having relationship with protozoa. R. E. Grant studied the morphology and physiology of sponges in greater details (1825) and framed the group Porifera. Huxley (1875) and Sollas (1884) wanted the sponges to be excluded from metazoan. These views were ignored till the middle of twentieth century, when they were treated as a separate branch called *Parazoa*. Recently Tuzet (1963) has expressed the view that though sponges possess many primitive features, yet there is no doubt that they are in the direct line of metazoan evolution.

HABITAT

The Phylum Porifera includes nearly 5000 described species.

Most of them are marine excepting 150 fresh water sponges of the family Spongillidae. These sedentaric animals usually stay in low depths and use solid surface

for fixation, but glass sponge reaches at greater depth and anchors on soft sediments. *Cliona* bores on the molluscan shell and is known as boring sponge. Sponges may be of varied colours and their shape depends upon the sites of their stay. The largest sponge is *Spheciospongia vesparum* having a diameter of two metres. Certain sponges, e.g. *Tethya* can contract its entire body, while in most cases the contractility is restricted around the osculum. During unfavourable condition most sponges shrink and form restitution bodies, which grow in favourable condition. In fresh water sponges specialised bodies called *gemmules* are formed for the same purpose. The gemmules remain viable for a period ranging from two months to three years. Many annelids and crustaceans live as symbionts with sponges. The body of sponge harbours many blue green and green algae. The well-known enemies of sponges are coral-reef fish, limpets and nudibranchs.

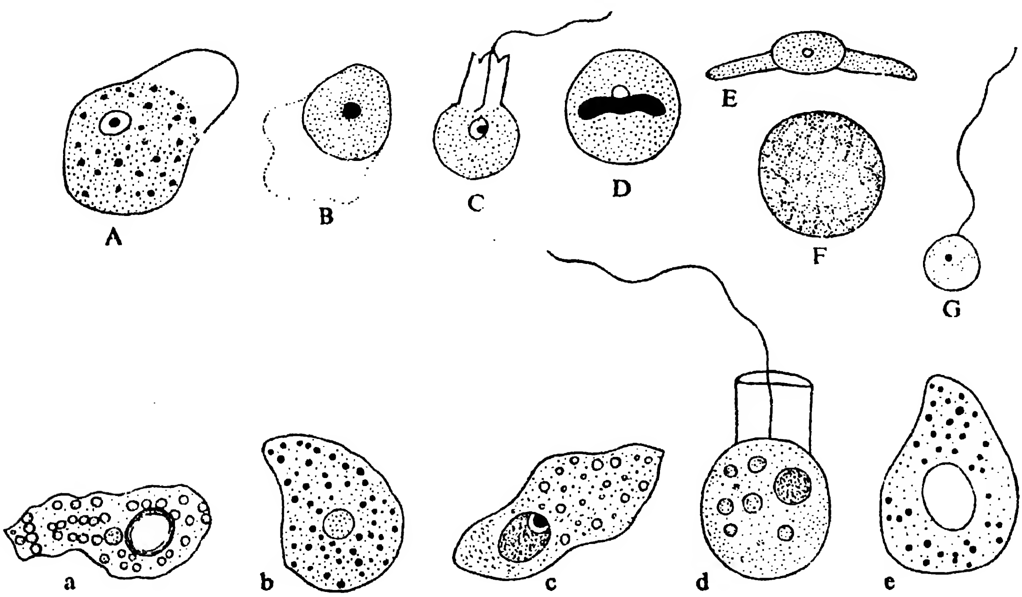


Fig. 10.7. Various cell types in sponges. A–G. From fresh water sponge. a–c. From *Microciona*. d. From *Scypha*. e. From *Leucosolenia*. A. Archaeocyte. B. Amoebocyte. C. Choanocyte. D. Scleroblast. E. Pinacocyte. F. Egg cell. G. Sperm cell. a. Globoferous amoebocyte. b. Granular amoebocyte. c. Archaeocyte. d. Choanocyte. e. Amoebocyte.

STRUCTURAL PECULIARITIES IN SPONGES

There are various types of sponges ranging from simple to complex. They have all in common certain structural features. The body is composed of loose aggregation of various types of cells (Fig. 10.7) which hardly form any tissue. There is no organ or organ system. They lack mouth and digestive cavity. Vital functions are performed by independent activities of the cells. In simple asconoid sponges the wall is composed of an outer *dermal epithelium* or *epidermis* and an *inner epithelium* consisting of *Choanocytes*. A mesenchyme containing skeletal spicules and several types of free amoeboid cells are present between the epithelia. The spicules support the body wall and hold the sponges erect. The mesenchymal cells originate from the outer epithelium, hence it may be considered as *ectomesoderm*. The body surface is perforated by pores acting for ingress of water.

Pinacocytes. The surface of the body or epidermis is lined by *pinacocytes*. Each pinacocyte is a large flat polygonal cell. The central part of the cell is thickened due to the placement of nucleus. Pinacocytes may also line the spongocoel and incurrent canals of syconoid sponges and also the spaces in leuconoid sponges. Such pinacocytes are sometimes referred to as *endopinacocytes*. Pinacocytes are highly contractile cells and can reduce the surface area of sponges. In many sponges a definite epidermis is absent as in Hexactinellida. It may form a syncytium in some cases.

Porocytes. The *pore cells* or *porocytes* occur among the pinacocytes at frequent intervals. The porocytes are usually regarded as transformed pinacocytes but Prenant (1925) opines that the porocytes are the derivatives of amoebocytes. Porocytes are tubular cells extending from the epidermis to the spongocoel. They are pierced by a central canal which acts as an incurrent passage. The cytoplasm of these cells contains many round inclusions. The porocytes are also highly contractile. The closure of the pore is effected by the advancement of a thin cytoplasmic sheet called the *pore diaphragm* from the margin to the centre at the outer end of canal.

Choanocytes. Inner surface of the body is lined by specialised cells, the *choanocytes*. The collar cells or choanocytes are specialised cells with a rounded or oval base resting on the mesenchyme and a contractile transparent collar which encircles the base of a single long flagellum. These cells are much larger in size in Calcarea than in other sponges. Spicules are formed by the deposition of the scleroblasts.

Mesenchyme. The mesenchyme is commonly called the mesoglea. The mesoglea consists of a transparent gelatinous matrix of protein nature in which different types of cells like *archaeocytes*, *amoebocytes*, *scleroblasts* and *germ cells* are present. The mesoglea is divided into two types: (*i*) *Collenchyma* and (*ii*) *Parenchyma*. When the mesenchyme contains few cells—this is called collenchyma. The mesenchyme with many cells is designated as parenchyma.

Amoebocytes. Amoebocytes are amoeboid in nature. They perform various functions and are responsible for producing other cell-types by the process of transformation excepting possibly the choanocytes. The amoebocytes are most important cellular entities in the life of sponges. The amoebocytes are of several varieties in different sponges. The types are: (*i*) *Collencytes:* amoebocytes with slender and branching pseudopods. (*ii*) *Chromocytes:* with lobose pseudopods and pigmented cytoplasmic inclusions. (*iii*) *Thesocytes:* with lobose pseudopods and many food reserves. (*iv*) *Scleroblasts:* producing skeleton and subdivided into (*a*) *Calicoblasts*, (*b*) *Silicoblasts* and (*c*) *Spongioblasts* according to the nature of secreted skeleton. (*v*) *Archaeocytes:* The amoebocytes with blunt pseudopods, conspicuous nuclei with large nucleolus are referred to as the archeocytes. The archeocytes are actually the generalised amoebocytes which play the dominant role in regeneration, reproduction and differentiation of other cell-types. Besides these cell-types long slender cells called the *desmocytes* are present specially in Demospongiae. Many fusiform contractile muscle cells or *myocytes* are present around the osculum.

CANAL SYSTEMS IN SPONGES

The structural complexities in sponges are primarily due to possession of canal system. This system constitutes the most vital system, because all the cell types work on the background of this system. So consideration of the different types of canal systems seems to be all the more necessary.

It has already been discussed that sponges bear a large number of pores on their body surface which lead into a system of channels permeating almost the whole body and ultimately open to the exterior. Canal system in sponges ranges from a very simple grade to highly complex type. The following types of canal systems are encountered in different sponges (Figs. 10.8 and 10.9).

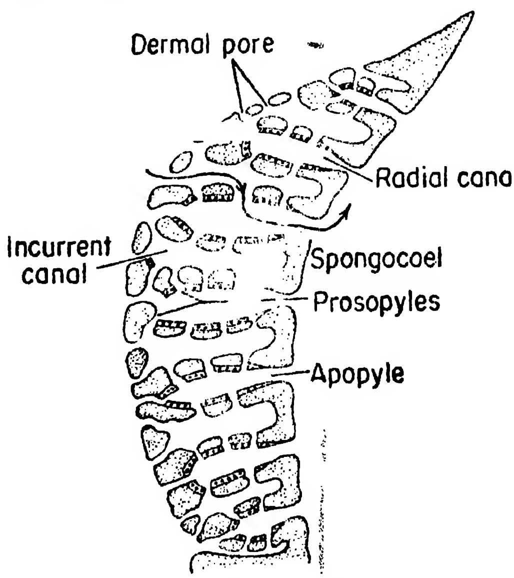


Fig. 10.8. Showing the Syconoid (Stage II) Canal system in sponge.

ASCONOID TYPE. The asconoid type of canal system is regarded to be the most simple grade of canal system. Asconoid type is present in these sponges whose body is vase-like and radially symmetrical. The wall is extremely thin.

It encloses a large spongocoel opening at the summit by a narrow osculum. The spongocoel is lined by choanocytes. The wall is pierced by numerous microscopic apertures termed as the *incurrent pores* or *ostia* which extend from the external surface to the spongocoel. Each pore is intracellularly disposed in a porocyte. The asconoid type of canal system is characterised by the presence of a complete continuous lining of choanocytes interrupted only by the porocytes. The course of water current is as follows:

Dermal pores → Internal ostia → Spongocoel → Osculum → Exterior → Dermal pores

Ascon type

SYCONOID TYPE. The syconoid type of canal system represents the transitional grade between the simplest ascon type and more complex ones. The first step above the asconoid type of canal system is represented by the syconoid type of canal system. The complication is due to the outpushing of the wall into finger-like projections called the *radial canals* at regular intervals. In this type of canal system, choanocytes are only limited to the radial canals. Their detailed account has already been described with the biology of Sycon. The syconoid canal system is represented by two grades:

(*i*) Syconoid (Stage I)
(*ii*) Syconoid (Stage II)

Syconoid (Stage I): The Syconoid (Stage I) type of canal system is found in the heterocoelous calcareous sponges typified by *Scypha* where the cortex is not formed. The radial canals are the free projections of the wall and the external surface is composed of the blind outer ends of the radial canals. The incurrent canals have not definitely formed and the spaces between the radial canals serve as the dermal ostia.

Syconoid (Stage II): The Syconoid (Stage II) canal system is found in many genera of calcareous sponges, viz. *Grantia*, *Grantiopsis*, *Heteropia*, *Ute*, etc. The complication is due to the spreading of the dermal membrane (consisting of epidermis plus a thin layer of mesenchyme) over the entire surface of the sponges to form the cortex of variable thickness. The walls of the radial canals fuse in such a fashion that tubular spaces (*incurrent canals*) are formed which open to the exterior through *dermal ostia* or *dermal pores*. The incurrent canals traverse along irregular course through the cortex before reaching the outer ends of the radial canals. Sometimes large irregular cortical spaces or *subdermal spaces* may be produced (Fig. 10.8).

LEUCONOID TYPE. In this type of canal system the choanocyte lining of radial canals evaginates into many small chambers which repeat the same process to give rise to a cluster of small flagellated chambers. In many cases dermal pores open into subdermal spaces. The subdermal space and incurrent canals lead into the small rounded flagellated chamber through an opening termed as *prosopyle*. The flagellated chambers open by *apopyles* into excurrent canals which form large tubes. The largest one leads to osculum. Few gradations of leuconoid type of canal system are seen in sponges. They are:

(*i*) **Eurypylous type.** When apopyles are in direct communication with excurrent canals by broad mouth.

(*ii*) **Aphodal type.** When a slender canal called *aphodus* connects the chamber to the excurrent canals.

Dermal ostia → Subdermal spaces and many incurrent canals → Prosodus (when present) → Prosopyles → Flagellated chambers → Apopyles → Aphodus (when present) → many excurrent canals → Large canals Leuconoid type → Osculum → Exterior → Dermal ostia

Leuconoid type

(*iii*) **Diplodal type.** When a narrow tube, the *prosodus* is present between the incurrent canals and the flagellated chambers. The scheme of circulation is shown above.

The main advancement of leuconoid canal system over that of syconoid type of canal system is due to:

(*i*) the limitation of choanocytes only to the small chambers,

(*ii*) the gradual development of the mesenchyme and

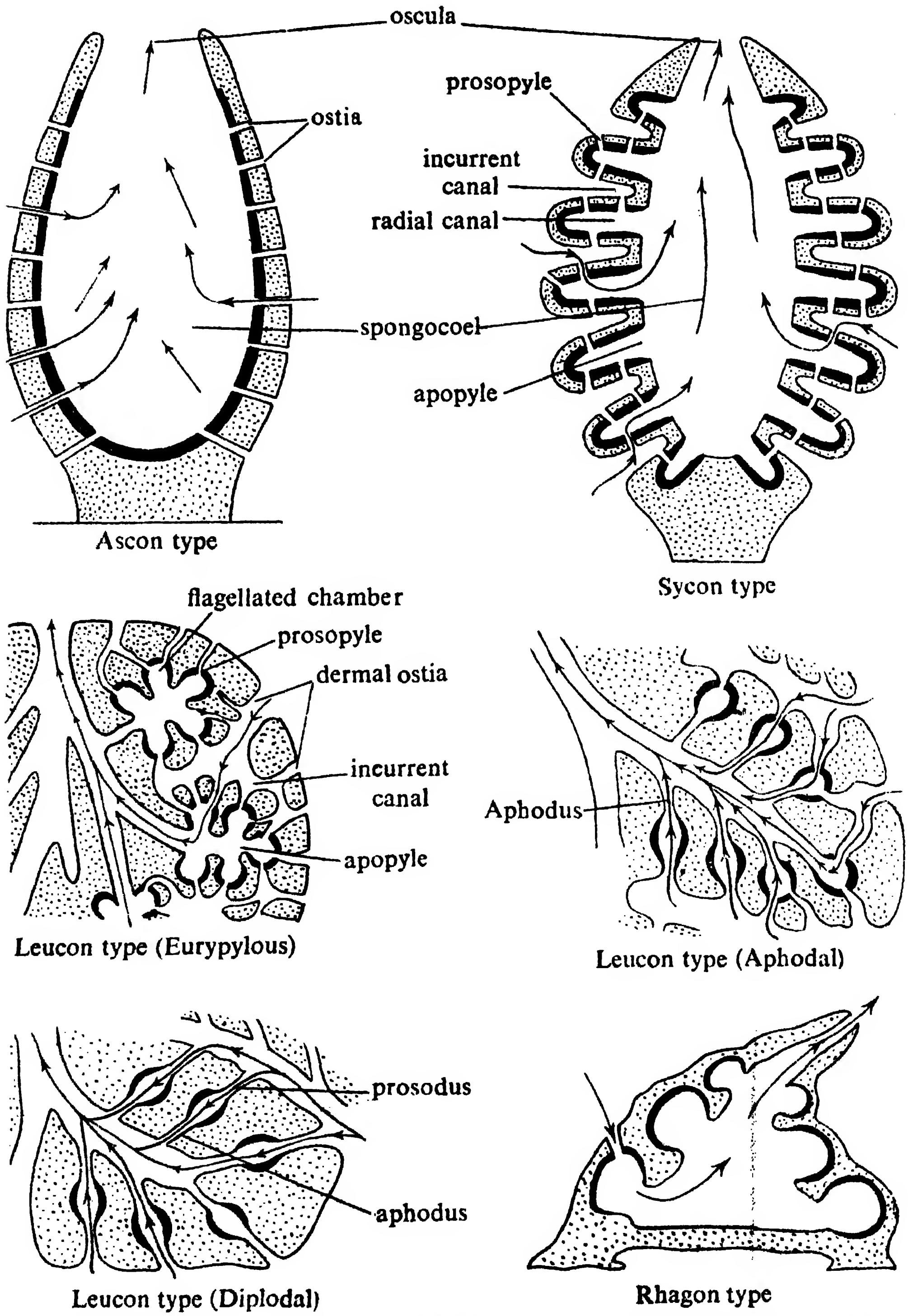


Fig. 10.9. Schematic representation of canal system in sponges. The sycon type of canal system drawn here actually represents the syconoid (Stage I) type. Dark bands indicate choanocyte layers and arrows denote the course of water flow (after Hyman).

(*iii*) the elaboration and complication of the incurrent and excurrent water passages.

RHAGON TYPE. The body is conical with osculum situated at the summit. The spongocoel is bordered by oval flagellated chambers, opening into it by wide apopyles. Between the epidermis and the chambers lies a considerably thickened mesenchyme which is traversed by incurrent canals and subdermal spaces.

The differences between four basic types of canal system in sponges are shown in Table 1—Porifera.

TABLE 1—PORIFERA

POINTS	ASCONOID TYPE	SYCONOID TYPE	LEUCONOID TYPE	RHAGON TYPE
1. Wall	Simple.	Evaginated to produce radial and incurrent canals.	Irregular.	Simple.
2. Mesenchyme	Simple and thin. Completely traversed by porocytes.	Thickened and not completely traversed by porocytes.	Highly elaborated, traversed by incurrent canals or subdermal spaces.	Considerably thickened, traversed by incurrent canals and subdermal spaces.
3. Choanocytes	Lined the spongocoel.	Limited to the radial canals.	Limited to the flagellated chambers. Flagellated chambers open by narrow apopyles.	Limited to the flagellated chambers which open by wide apopyles.
4. Spongocoel	Spacious.	Spacious.	Usually obliterated.	Spacious.

Canal system in sponge furnishes a peculiar kind of pump, driving in and out the current of water. A sponge, called *Callyspongia* having a body of 10 cm. long and 4 cm. diameter, pumps 78 litres of water in a day. Another sponge, *Leuconia aspera* having almost an identical body, drains 22·5 litres. A flow of water through the body is essential because there is no other fluid circulating in the body. It supplies food and oxygen and helps to remove waste products. Water current is caused by the beating of the flagella of the choanocytes. But, as the flagella do not beat in co-ordination, how such a synchronous flow of water current is produced is not clearly understood.

SKELETON

The skeleton in sponge is a very peculiar cellular derivative. The origin, structure and significance of the skeleton in sponges are very difficult to explain. The skeletal elements found in sponges can be divided into two types:

Spongin. The spongin comprises of fibres of *spongin* and they resemble silk in appearance. These are proteinaceous secretion of the spongioblasts and form a network. In most cases, the spongin fibres are composed of protein termed spongin-B. In some cases the fibres are composed of collagen called the spongin-A.

Spicules. The *spicules* or *sclerites* have definite bodies consisting of spine or spines radiating from a point. Each spicule consists of an axis of organic material around which inorganic substances are deposited either in the form of calcium carbonate or hydrated silica. They exhibit a great

variety of form and shape. The spicules are broadly divided into two principal types depending on size. These are:

(*i*) *Megascleres* or the large skeletal spicules and (*ii*) *Microscleres* or the small spicules. The megascleres actually form the chief skeletal framework of the sponges. The microscleres are present throughout the mesenchyme. But such division of the spicules on the basis of size, is not regarded to be accurate. They are best classified into different types according to the number of their axes and rays (Fig. (10.10). The types of spicules recorded below are mainly based on the above criteria:

Monaxon type. They are formed by the growth in one or both directions along a single axis. The axis may be straight or may be curved. The monaxon type of spicules is of two kinds: (*i*) *Monactinal monaxon,* when the growth occurs in one direction and (*ii*) *Diactinal monaxon,* when growth occurs by proliferation in both directions from a central point.

Tetraxon type. This type of spicule consists typically of four rays radiating from a central point. Subsequently by loss of ray or rays, they may secondarily become three, two or one-rayed. There are several varieties of tetraxon spicules. These are: (*i*) *Calthrops:* When the four rays are almost equal, (*ii*) *Triaenes:* When one ray is elongated (*rhabdome*) and other three are short (*cladome*), (*iii*) *Diaenes:* When one of three cladi is lost and (*iv*) *Triradiate:* a special type of triaene where the rhabdome is lost.

Triaxon type. This type of spicule is fundamentally composed of three axes which cross at right angles and produce six rays (*hexactinal*) arising from a central point.

Polyaxons. When several equal rays radiate from a central part, the spicules are called polyaxon type. The polyaxons are divided into two broad categories: (*a*) with small centres and long rays and (*b*) large centres with small rays. The first category of spicules is subdivided into: (*i*) *Oxyasters* (pointed rays), (*ii*) *Strongylasters* (rounded ends) and (*iii*) *Tylasters* (knobbed rays). The second category is subdivided into : (*i*) *Spheraster* (with definite rays) and (*ii*) *Sterrasters* (with reduced rays).

Spheres. The spicules under this category are rounded bodies where growth occurs in concentric manner around a centre.

Desma. This type consists of minute monaxon or triradiate tetraxon spicule called *crepis* on which layers of silica have been deposited irregularly. The desmas are classified into four types depending on the shape of the crepis. These are: (*i*) *monocrepid,* (*ii*) *tricrepid,* (*iii*) *tetracrepid* and (*iv*) *lithistid desmas.* The first three types have

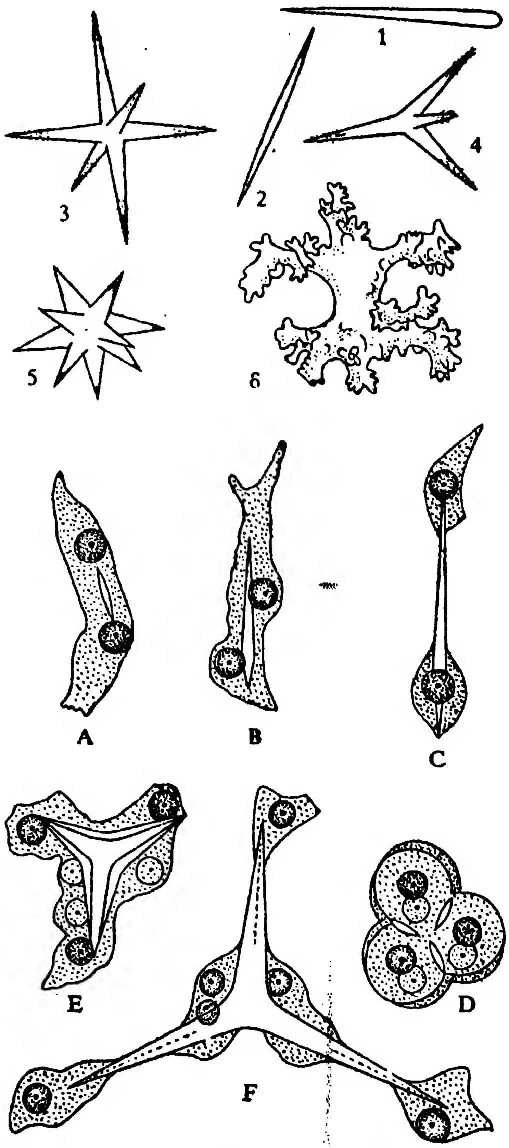


Fig. 10.10. A few types of spicules of sponges. 1. Monaxon-style. 2. Monaxon diactinal-oxea. 3. Triaxon-regular hexactine. 4. Tetraxon-calthrops. 5. Polyaxon-oxyaster. 6. Desma. A-C. Development of monaxon spicule. D-F. Formation of triradiate spicule. Note that the founder cells are present at the centre of the developing spicule and the thickener cells are located at the tip of the rays. (after Hyman).

monaxon, triradiate and tetraxon crepis while the fourth variety is formed by the union of the first three varieties in the form of a network.

Development of spicules. Spicules are the secretory products of the *scleroblasts.* The origin of calcareous spicule is clearly known. The formation of monaxonic calcareous spicule begins as minute deposition of calcium carbonate in the interior of a binucleate scleroblast laid down around an organic axial thread. Spicule begins to be deposited between the two nuclei which ultimately separate the cell into two. Of the two cells, one is known as the *founder cell* and the other cell is designated as the *thickener cell*, which deposits additional layers of calcium carbonate. In the formation of triradiate spicule three scleroblasts participate and act more or less in the same way. Figure 10.10 (A-F) shows the formation of monaxon and triradiate spicules. As regards the development of siliceous spicule details are not clearly known.

Taxonomic significance of spicules in sponges. Existence of spicules in sponges helps the taxonomists greatly in arranging the diverse species of sponges into regular and definite orders. Classification of sponges is largely based on the type of spicules they possess. It is interesting to note that in porifera evolution has taken place in the mesenchyme and not in the epithelial layer.

AFFINITIES OF SPONGES

Sponges represent the oldest form of metazoa. Fossil sponges were discovered from beds of Europe, Asia and North America, which are more than 600 million years old. The most widely known fossil genus is *Archaeocyathus.* No one questions the multicellular nature of sponges. The close similarity with colonial protozoans like *Proterospongia*, unequivocally speaks about the protozoan affinity of porifera. The protozoan affinity is attested by the following evidences: (1) Absence of formed tissues; (2) the presence of choanocytes; (3) mode of secretion of skeleton within single cell; (4) similar nature of nutrition; (5) existence of totipotency of cell-types; and (6) lack of cellular integration. The sponges exhibit close protozoan affinities but the attempts to include sponges under the Phylum Protozoa failed because of the development of germ layers in developing sponges. Solas proposed to place the sponges under a subkingdom, the *Parazoa* as an isolated branch of the Metazoa. Recent work have established that the sponges are metazoan of lower grade of organisation. But their inclusion in the direct line of metazoan evolution has been thrown into doubt because they do not possess the following basic organisations of metazoa:

1. *At morphological level.* The participating cells must remain arranged in layers and some amount of division of labour should be there. Certain amount of organisations like connective tissues, nervous tissues, are expected to be present even at the simplest form.

2. *At physiological level.* In a true metazoa, each function should be carried by a group of cells. The outer layer of cells is primarily responsible for protection and inner layer of cells carries on the nutritive functions. There must be distinct differentiation of somatic and germinal parts of the body.

3. *At embryological level.* A true metazoa will develop from a unicellular zygote and will pass through stages like blastula and gastrula. It is in the gastrula stage three primary germinal layers are differentiated and the blue print of future organisation is laid. Once differentiated, the germinal layers are irreversible in nature.

Unlike other metazoans reversal of germ layer takes place in sponges.

On the contrary, there are certain features in sponges which may be considered as unique to them These features are:

1. Within the sponge body each cell is an autonomous unit, i.e. each cell is independent and self-centered.

2. The osculum in sponge apparently resembles the mouth of coelenterates, but developmentally the osculum does not correspond with it.

3. The spongocoel corresponds to the coelenteron of the coelenterates but pores and network of choanocyte-lined canals are not seen in any metazoan group.

4. The mesoglea is poorly defined and contractility is restricted only to the region of the osculum.

5. The ability of amoeboid cells to become another cell-type—speaks that in the group of sponges determination is not rigid like other metazoans.

For this reason, the sponges were considered by L. H. Hyman as a blind lane from the high way of metazoan evolution and thus a new term "Parazoa" was coined to include them in a separate subdivision under the subkingdom Metazoa.

Such inclusion has recently been challenged by O. Tuzet ("The lower Metazoa" E. Dougherty, Univ. of Calif., 129-148, 1963), who after studying sponges for many years has again claimed that porifera has given rise to the true metazoans. This idea takes following facts into consideration:

1. Choanocyte cells are seen in some echinoderms, therefore, are not the only characteristic of sponges. The flagellate cells in the inner lining of the cnidarians also bring a close resemblance.

2. The processes in gametogenesis, i.e. production of sperm and ovum, are same as in other metazoans.

3. The metazoan affinity obtained greater support from the study of spongin which has chemical and physical resemblances with the collagen.

4. The development of sponges like *Oscarella* shows similar processes as in metazoa. The cleavage of zygote results into a blastula stage (coeloblastula) which by invagination becomes gastrula.

5. The constituent cells exhibit less differentiation but are involved in several complicated organisations, i.e. formation of gemmules.

6. The unrestricted power of regeneration speaks about the primitiveness of sponges. The comparative study of regeneration has revealed that the power of regeneration decreases with the progress from lower to higher groups of animals. In most of the cases certain 'embryonic' cells resembling the amoeboid cells of sponge play important role during regeneration.

Thus sponges are again proposed to be shifted in the high way of metazoan evolution and have been placed in between protozoa and cnidarians as phylum Porifera (Fig. 10.11). The fact that the sponges evolved from the Protozoa and occupy a position between the Protozoa and Cnidarians is evidenced by the follownig arguments:

(1) The choanocytes are diagnostic to the anatomy of sponges. Identical cells, as already stated, are present in many protozoans, echinoderms, annelids and molluscs.

(2) The peculiar event in fertilisation that two synergids direct the sperm towards the egg is found to occur in chaetognatha.

(3) The tetra-radial symmetry exhibited by the larvae of calcareous sponges is comparable with that of the larvae of polychaetes, sipunculids and gastropods.

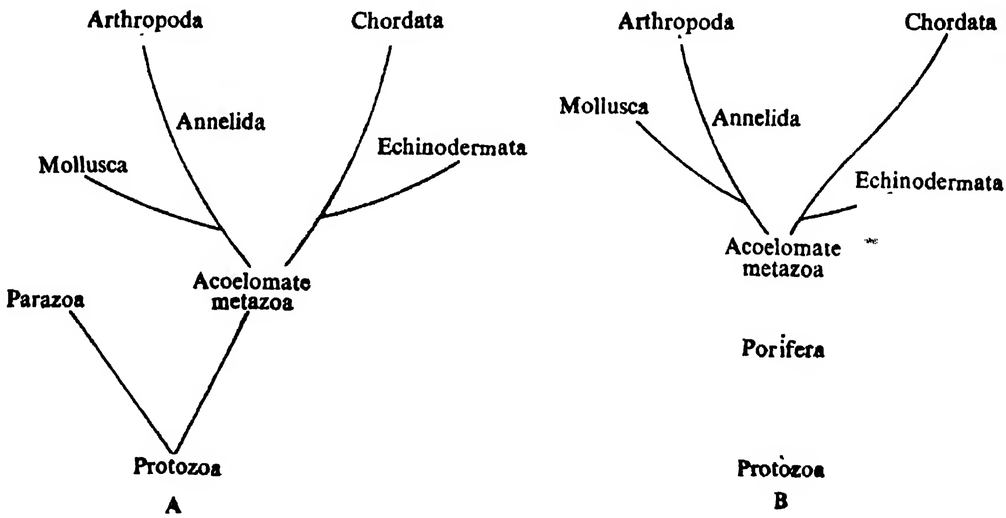


Fig. 10.11. Phylogenetic position of sponges. A. Hyman's view. B. Tuzet's view.

(4) **Existence of wide regenerative** power in sponges and in many lower metazoans.

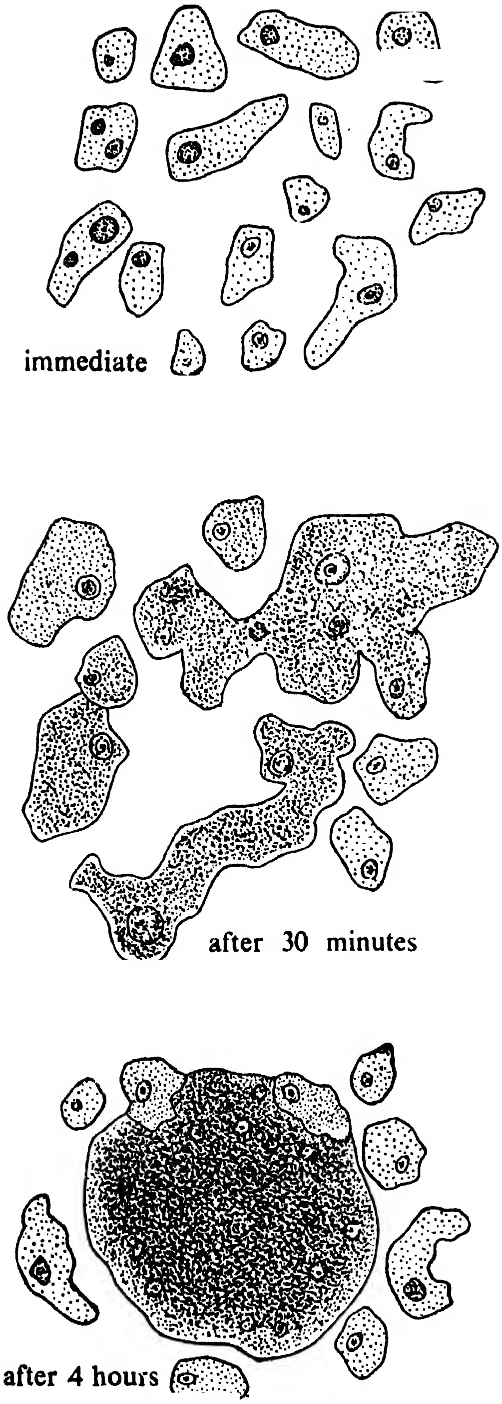


Fig. 10.12. Events of aggregation of dissociated cells of sponge. Note that individual cells unite to form small aggregates, small aggregates continue to fuse both with other similar aggregates and individual cells (after Ganguly).

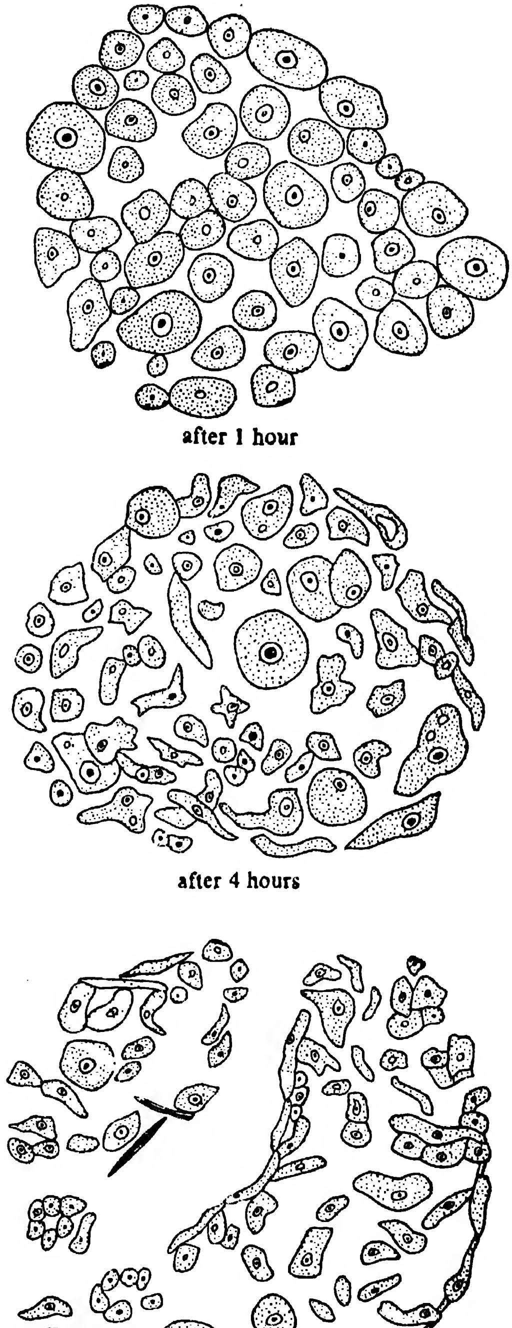


Fig. 10.13. Cellular changes within an aggregate during regeneration (sectional view)—after Ganguly.

(5) The developmental dynamics of calcareous sponges show close parallelism with that of *Volvox*. This point strengthens the idea that the colonial flagellate protozoans hold the key to the evolution of the sponges.

REGENERATION IN SPONGES

Sponges can regenerate their lost parts very rapidly. H. V. Wilson (1907) for the first time demonstrated that a bit of sponge when squeezed through a silken mesh dissociates completely. Such dissociated cells, if kept under water, aggregate again and form the sponge body. Such property of sponge has later been seen by several workers in different marine and fresh water sponges. The following incidences happen during reaggregation of sponges:

1. At the dissociated stage, amoeboid cells (archaeocyte and amoebocyte) and flagellate cells (choanocytes) show movement (Fig. 10.12).

2. The amoeboid cells (specially the archaeocytes) start to contact with each other and with other types of cells. This continues for 4–6 hours. At first, small aggregates of 4–8 cells are formed. Gradually small aggregates meet other cells or other similar aggregates and grow in size.

3. Within the aggregate, all the cells lose their identity and become homogeneous. This phenomenon is called dedifferentiation (Fig. 10.13).

4. Gradually the peripheral cells of the newly formed aggregate form pinacocytes. This is followed by the appearance of flagellate cells, formation of spicules and establishment of canals within the aggregate.

5. It has been noted that excepting amoeboid cells, the other cell-types do not have the ability to be transformed into another type of cell. Thus from dedifferentiated state, pinacocytes, choanocytes and scleroblasts return to their original form. But amoeboid cells may be transformed into any other cell-type. For this reason amoeboid cells are regarded as *totipotent* cells.

WHY STUDY SPONGES ?

Formerly sponges were adored only for the commercial value of spiculeless forms. Sponge cultivation for yielding sponges from cuttings is done with success in coastal regions of Mediterranean, Atlantic and Pacific oceans. Before the coming of synthetic bath-sponge, these natural sponges had great market value. Some sponges are also important for decoration and ornamentation.

Recent work on its regeneration and development have made it an excellent material for studying cellular behaviour in the problems of developmental biology. Such studies hold promise for exploring various problems, related to connective tissue diseases, cancer research and tissue transplantation.

SUMMARY

1. Phylum Porifera includes animals having pores in the body wall.
2. The first step towards multicellularity is encountered in sponges.
3. The most specialised structures present in this group are canals, flagellated chambers, spicules and gemmules.
4. Definite organ in any form is absent.
5. Internal cavity in most of the forms is lined with a special type of cell called choanocytes.
6. Canal systems present in different forms offer an interesting study regarding evolution of structural complexity.
7. Spicules present in different forms constitute the basis for classification.
8. Some species belonging to this phylum are the sources for bath sponges and are of economic importance.

CHAPTER 11

Phylum Cnidaria

If sponges are the first step towards multicellularity, then the cnidarians are definitely one more step advanced in having tissue grade of structural organisation. The variety of forms which are included under this phylum are distributed throughout the world. All the members possess certain features which are absolutely unique to this group. It was a common older practice to include the members of the phyla Cnidaria and Ctenophora under a common phylum Coelenterata. The phylum Coelenterata owes its name from the *Coelenteron*, an internal cavity lined by endoderm. But the recent researches on this line have rendered considerable support to the contention of separating the two groups as discrete phyletic entities. The phylum Cnidaria has an ideal diploblastic condition (Fig. 11.1) while the phylum Ctenophora shows triploblastic condition.

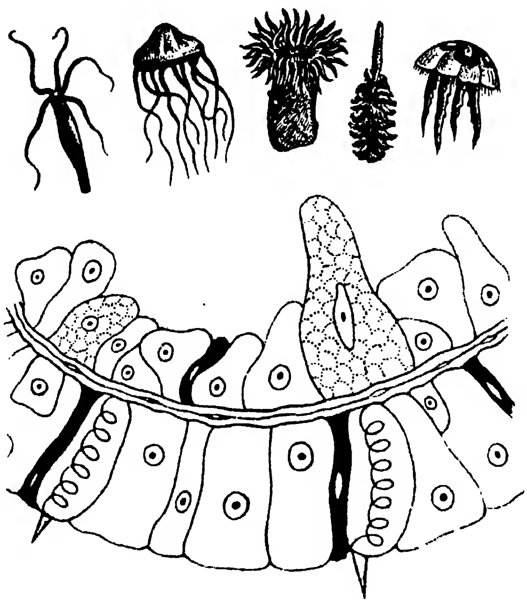


Fig. 11.1. All cnidarians have two layers of cells.

IMPORTANT FEATURES

1. The cnidarians exist in two forms —*Polyp* (representing *asexual* phase) and *Medusa* (representing *sexual* phase). The body of polyp is tubular and it usually remains fixed at one end called the *aboral* end. The free end of polyp possesses a conical elevation called *hypostome* or *manubrium*, at the centre of which lies the opening called *mouth*. The mouth is surrounded by a circlet of *tentacles*. The free-swimming medusa possesses dorsal convex *exumbrellar* surface and a ventral concave *subumbrellar* surface. From the centre of the ventral side a tube extends like the stick of an umbrella, called the hypostome or manubrium. Tentacles are present around the manubrium and also along the margin of the medusa. (Fig. 11.2).

2. All the members are aquatic and most of them are marine.

3. The body is composed of two cellular layers and hence they are called *diploblastic* animals.

4. Highly specialised intracellular structures called the *nematocysts* are present.

5. They usually exhibit radial symmetry in adult stage.

6. Presence of a single internal *coelenteron* which represents the general body-cavity and the enteric cavity.

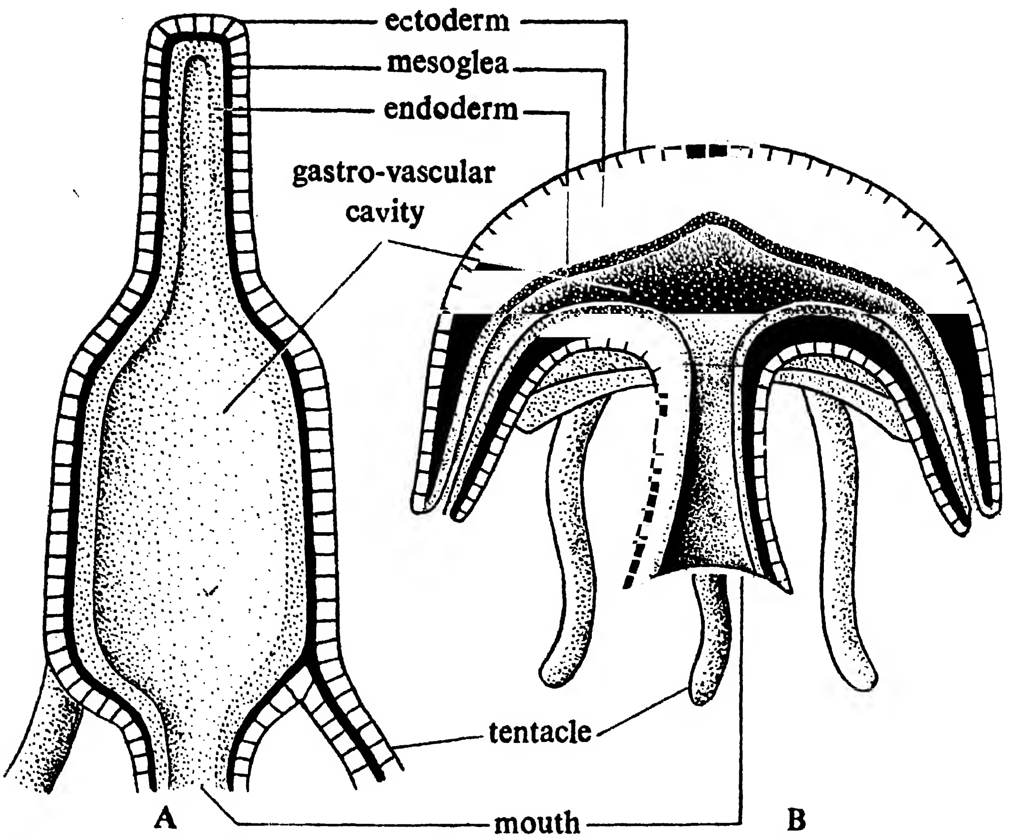


Fig. 11.2. Primary body forms of cnidarians: polyp (A) and medusa (B) in diagrammatic longitudinal sections. Polyp is drawn in inverted state.

7. Presence of only one permanent aperture—the mouth which also functions as anus.

8. Both *intracellular* and *extracellular* types of digestion are present.

OUTLINE CLASSIFICATION

The Phylum Cnidaria is divided into three classes: *Hydrozoa*, *Scyphozoa* and *Anthozoa*. The division of this phylum into three classes is universally accepted. The Scyphozoa is included by some authors under Hydrozoa, but considering their affinity with Anthozoa it is preferred by many to keep it separate from Hydrozoa.

Example of the Phylum Cnidaria—*HYDRA*

HABIT AND HABITAT. One of the smallest solitary polyps amongst the cnidarians is represented by *Hydra*. Almost all the hydras inhabit clear, transparent fresh water ponds and lakes excepting *Protohydra* which is marine. Hydra owes its name from Greek mythology where the sea-serpent named **Hydra** had the inherent potentiality to regenerate its head, if extirpated.

Several species of hydra are recorded. The common Indian species is the *Hydra vulgaris* (formerly known as *Hydra grisea*) and the *Pelmatohydra oligactis* (formerly called as *Hydra fusca*). The phase *orientalis* of *Hydra vulgaris* is the commonest variety present in the neighbouring ponds of Calcutta. *Pelmatohydra oligactis* has a comparatively slender body and the length of the tentacles exceeds three to four times the length of the body column. Another form of hydra which needs mentioning here is *Chlorohydra viridissima* (formerly known as *Hydra viridis*). This species harbours symbiotic algae *Zoochlorella* in the endodermal cells which render the colour of the body green. Certain parasites are recorded in hydra, namely *Hydramoeba hydroxena* and few ciliates, *Kerona pediculus* and *Trichodina pediculus*. All the forms of hydra are built on same basic pattern and the following

description will give an idea on the biology of hydra in general. Hydra exists only in polyp form (monomorphic) and the phenomenon of metagenesis or alternation of generation is totally absent.

STRUCTURE. Hydra has a slender tubular body and exhibits distinct radial symmetry (Fig. 11.3). The body is extremely

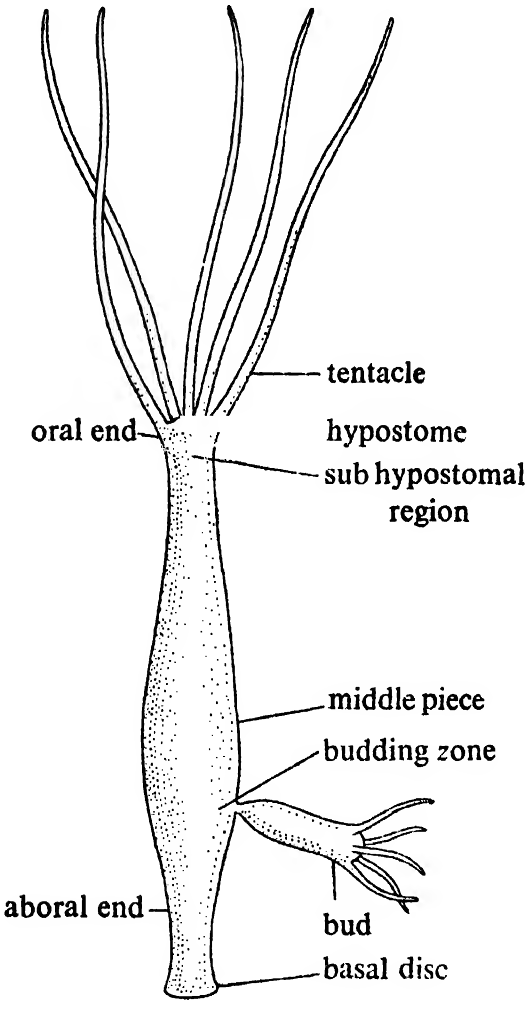


Fig. 11.3. *Hydra vulgaris*. External features. (courtesy: *Dr.* R. Palit).

contractile and the length varies from 10 to 30 mm. The lower end of the tubular body is closed and this side is designated as the *aboral* or *proximal* end. This end of the body is named as the 'foot' or *basal disc* which is used as a structure for attachment to the substratum and it aids in locomotion as well. The opposite end (the *oral* or *distal* end) is free and possesses the opening of the mouth, situated at the summit of a conical elevation called the *hypostome* or *manubrium*. The base of the hypostome is surrounded by a number of tentacles. The usual number of tentacles is six but it may vary from four to eleven in some cases. Tentacles are totally absent in *Protohydra*.

The mouth leads into the *coelenteron* which occupies the interior of the body and is also continuous with the slender cavities of the tentacles. In most cases, the fairly grown individuals bear buds located at the specific budding zone of the body, i.e. the region of the body column just below the middle of the body. During breeding season the mature individuals possess many male gonads or *testes* and usually one female gonad or *ovary*.

STRUCTURE AND FUNCTION OF THE DIFFERENT CELLULAR UNITS

The body of Hydra is composed of two cellular layers with a thin non-cellular *mesoglea* (Fig. 11.4) in between. The

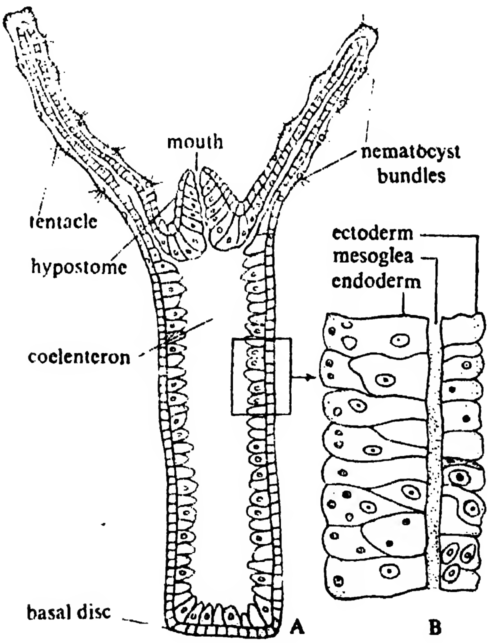


Fig. 11.4. A *Hydra* in longitudinal section (diagrammatic). B. A portion of the body wall is enlarged. (after Tardent).

outer layer is known as the *ectoderm* and the inner layer is known as the *endoderm*. In addition to the power of contractility common to both the layers, the ectoderm is mainly protective and the endoderm is primarily nutritive in function. Both the layers are constituted

of several cell-types, destined to perform diverse physiological functions (Fig. 11.5). In Hydra cellular differentiation is associated with the physiological division of labour. Each kind of cell performs definite and specific functions in co-operation with each other for the individual as a whole.

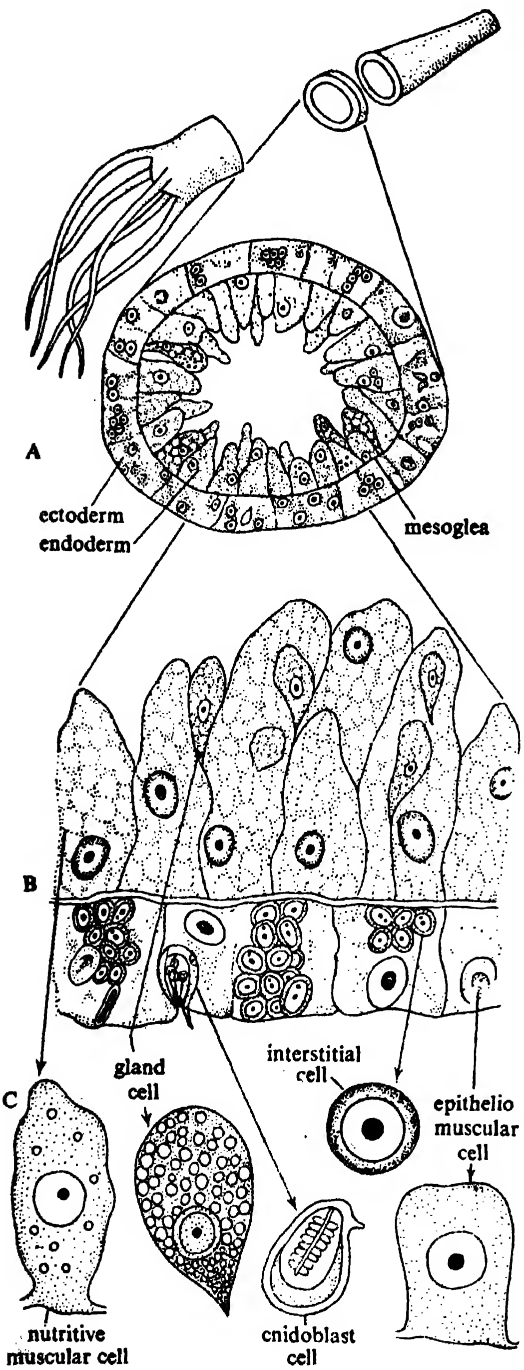


Fig. 11.5. A Transverse section of *Hydra vulgaris*. (after Mookerjee and Dutta). B. Arrangement of cells in the body wall. (after Mookerjee and Sanyal). C. Cell-types. (after Mookerjee and Sanyal).

I. **Ectodermal cell-types.** The ectoderm is composed of epitheliomuscular cells, interstitial cells, cnidoblasts, sensory cells, nerve cells and basal disc cells.

A. **Epitheliomuscular cells.** These cellular units constitute the main bulk of the ectoderm and are comparatively larger in size. The compound name of this type is due to its dual functioning capacities, protection and the power of contraction. The cells are roughly conical in shape having their broad ends directed outwards. These ends fuse and give rise to a continuous cuticle along the entire length of the body. The narrower ends are directed to the mesogleal side and are produced into contractile processes which are oriented along the length of the animal to act as longitudinal muscles. The contraction of these processes shortens the body column and tentacles. This cell-type has a prominent nucleus and several small vacuoles.

B. **Interstitial cells.** In the intercellular spaces between the narrower ends of the epitheliomuscular cells there are small cells called the interstitial or subepithelial cells. These are comparatively small in size and oval in shape. These cells usually occur in clusters. Each cell has a prominent nucleus with one or more distinct nucleoli and the cytoplasm is very inconspicuous. Interstitial cells can give rise to other cell-types, such as the cnidoblasts and sex-cells. For this reason these cells are known as perennially undifferentiated embryonic cells.

C. **Cnidoblasts.** This type of cellular unit constitutes a very important component of the ectoderm. The cell contains a sac-like *nematocyst* and a layer of specially contractile cytoplasm with distinct nucleus. From the outer end of the *cnidoblast* projects a trigger-like pointed process called the *cnidocil*. When touched, it conveys the sensation to the inner part of the cell. Each nematocyst is a fluid-filled rounded capsule, the narrow end of which is drawn into a long, coiled, thread-like tube. It remains immersed within the cavity of the nematocyst (Fig. 11.6). It can be everted to aid in capturing the

prey or in locomotion. Cnidoblasts may occur singly in the body column, but in the tentacles several smaller ones are grouped around a central one (penetrant type) to form small surface tubercle or 'battery'. Cnidoblasts have a characteristic regional distribution. They are quite numerous in the tentacles and anterior region of the

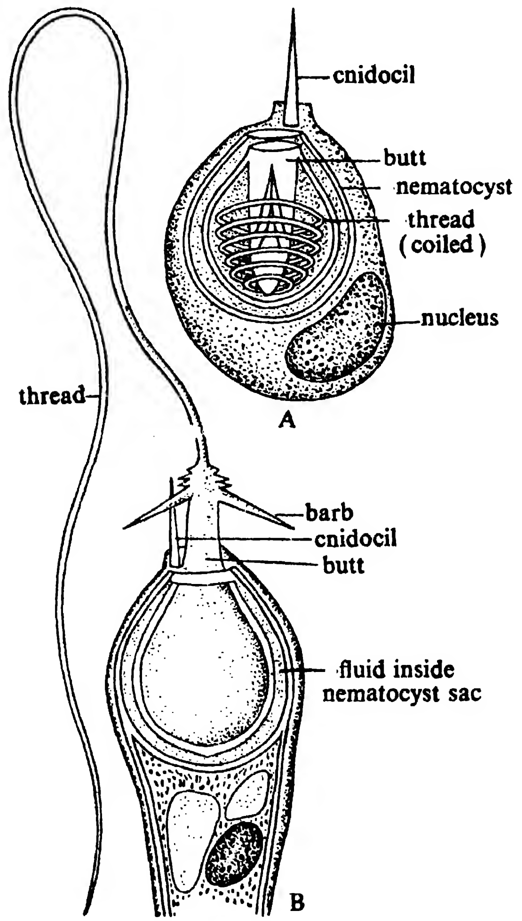


Fig. 11.6. Cnidoblast of *Hydra*. (after Parker and Haswell). A. Undischarged. B. Discharged.

body but gradually slide down towards the aboral side and are totally absent in the basal disc.

Usually four types of nematocysts are encountered in Hydra (Fig. 11.7). They are as follows:

Penetrant type or Stenotele: This type has a large spherical cell-body of about 16 micra in diameter. It has a long thread-like tube which remains coiled in transverse plane. The base of the thread contains three long *barbs* and bears rows of small thorns or *nettles*. When the cniodcil is stimulated the thread tube shoots out. It pierces the body of the prey and injects a fluid containing a toxic protein called *hypnotoxin* to paralyse the victim.

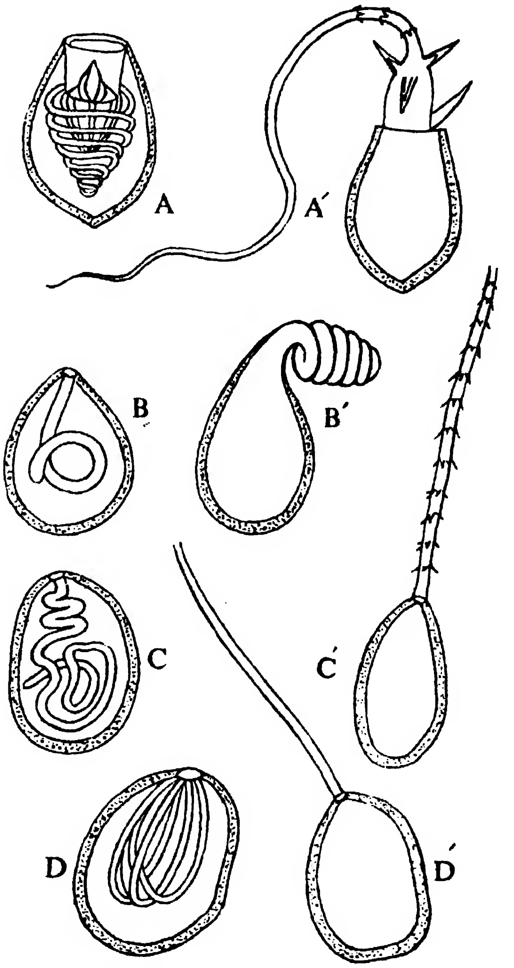


Fig. 11.7. Nematocyst types of *Hydra*. (after Buchsbaum).
A, A'—Penetrant; B, B'—Volvent; C, C'—Glutinant streptoline; D, D'—Glutinant stereoline.
A, B, C, D Undischarged, A', B', C', D' Discharged.

Volvent type or Desmoneme: They are pear-shaped forms having an average length of about 9 micra. Each nematocyst of this kind contains a thick short thread, which usually forms a single loop. After discharge the thread coils round any part of the prey.

Glutinant Streptoline type or Holotrichous isorhiza: They are oval in shape and are about 9 micra in length. Each nematocyst possesses a long thread with three or four

transverse coils and bears small nettles. The thread may coil after discharge.

Glutinant Stereoline type or Atrichous isorhiza: These types of nematocysts are comparatively smaller in size and are about 7 micra in length. Upon discharge the thread remains straight. The thread is unarmed.

The *penetrant* and *volvent* types of nematocysts help in capturing the prey and the *streptoline* and *stereoline glutinant* types, in addition to the capture of food, help in locomotion by producing sticky secretion.

Discharge of nematocysts. Cnidoblasts possess an independent effector. Any stimulus affecting the cnidocil directly causes the discharge of the thread. Opinions differ as regards the actual mechanism of discharge. Mechanical stimuli are not always found to be effective. Substances extracted from the crustacean larvae on which Hydra feeds provoke discharge of nematocysts. Acetic acid is seen to cause discharge of the nematocysts. The discharge of thread is caused by the increased osmotic pressure of the fluid within the nematocyst capsule.

Nematocysts once shot out are not incorporated in the body system. New cnidoblasts develop out of interstitial cells. Usually one cnidoblast develops from one interstitial cell, but often two or more may arise.

D. **Basal disc cells.** In the basal disc region the epitheliomuscular cells are modified into tall cells. These cells have deeply stained granules in the cytoplasm and have faint striations. These cells produce a sticky secretion which helps the animal to adhere to the substratum under water. Sometimes these cells also produce gas bubble which helps the animal to float in water.

E. **Sensory cells.** Scattered in the ectoderm there are numerous slender sensory cells. Several types of sensory cells are seen in Hydra. Sensory cells have delicate tips with sensory hairs. Sensory cells are quite abundant in the basal disc region, hypostome and tentacles. The bases of these sensory cells are connected to the nerve cells.

F. **Nerve cells.** Existence of nerve cells in the ectoderm of Hydra is a highly controversial issue. By special histochemical techniques, some workers on this line, have demonstrated the presence of spider-like cell-bodies, designated as the nerve cells. Delicate processes originating from the cell-bodies form a network in the ectoderm adjacent to the mesoglea. These processes are connected to the sensory cells, to the similar processes of other nerve cells and lastly, to the contractile fibrils of the epitheliomuscular cells. Such combination of nerve connection produces a sort of simplest sensory-neuromotor mechanism in animals. This system co-ordinates the movement of the body and tentacles.

II. **Endodermal cell-types.** The endoderm of Hydra is primarily made up of nutritivemuscular cells and gland cells. Interstitial cells and cnidoblasts occur very rarely in the endoderm. Sensory cells and nerve cells are also present in the endodermal layer as in the ectoderm.

A. **Nutritivemuscular cells.** The nutritivemuscular cells constitute the main bulk of the endoderm. They are tall columnar cells encircling the coelenteron. In the hypostome region, the cytoplasm of the nutritivemuscular cells is granular and homogeneous. But in the tentacles and in the basal disc regions these cells are highly vacuolated with little cytoplasmic content. In the rest of the stem body these cells are highly developed. The nucleus is usually located towards the mesogleal side and contains one or two nucleoli. Cytoplasm is less vacuolated. Deeply stained spherical bodies are abundantly found in these cells. The mesogleal ends of the nutritivemuscular cells are produced into contractile processes oriented transversely to encircle the body. These processes act as circular muscles. When contracted, the diameter of the body is reduced and consequently the length of the body is extended. Nutritivemuscular cells are of two types—*amoeboid* and *flagellated*. The broader end of amoeboid cells projecting in the coelenteron produces pseudopodia to engulf the particles of food. The cells with whip-like flagella cut the particles of the food into pieces. Recent observations have however, failed to record the presence of such flagellated cells. As stated earlier symbiotic Zoochlorella and some parasitic amoebae and coccidia are recorded amidst the endodermal cells, particularly the nutritivemuscular cells of some species of Hydra.

B. **Gland cells.** Gland cells are present all through the endoderm of Hydra excepting the tentacles. They are plenty in the oral region but their number gradually reduces towards the aboral region. They are usually located in between the nutritive-muscular cells. Two types of gland cells are encountered in the endoderm. The first category of the gland cells is smaller in size. The shape is oval. The end facing the coelenteron is broader and the other end is gradually narrowed to a thread-like projection touching the mesoglea. The cytoplasm is intensively basophilic and vacuolated. Nucleus is distinct and is situated at the narrow end of the cell. The second category of the gland cells exhibits less basophilic cytoplasm. Vacuoles of different sizes are dispersed within the cell body. Nuclei are not distinctly visible.

The above mentioned types of the gland cells also have characteristic regional distribution. The former category of the gland cells is quite abundant in the oral part of the body, while the other category has outnumbered them in the aboral region.

It has been observed that the distribution of various cell-types varies along the entire length of the body. The difference in cell-population at different zones of the body column indicates the presence of functional diversity in the different regions of the body (Fig. 11.8).

Cell flow in Hydra. It has been observed that Hydra loses its old cells through the basal disc and tip of the tentacle. New cells are believed to be formed in a region immediately beneath the hypostome. This subhypostomal region is called the '*growth zone*' of Hydra. The cells produced in this region migrate in two directions—one towards the tentacles and the other towards the basal disc. This phenomenon of two-directional cell-flow in the body of Hydra can be experimentally shown. Mookerjee (1962) has shown that a middle piece of Hydra, when grafted in the subhypostomal region induces a basal disc. Similar result has also been obtained by Sinha (1967) by implanting

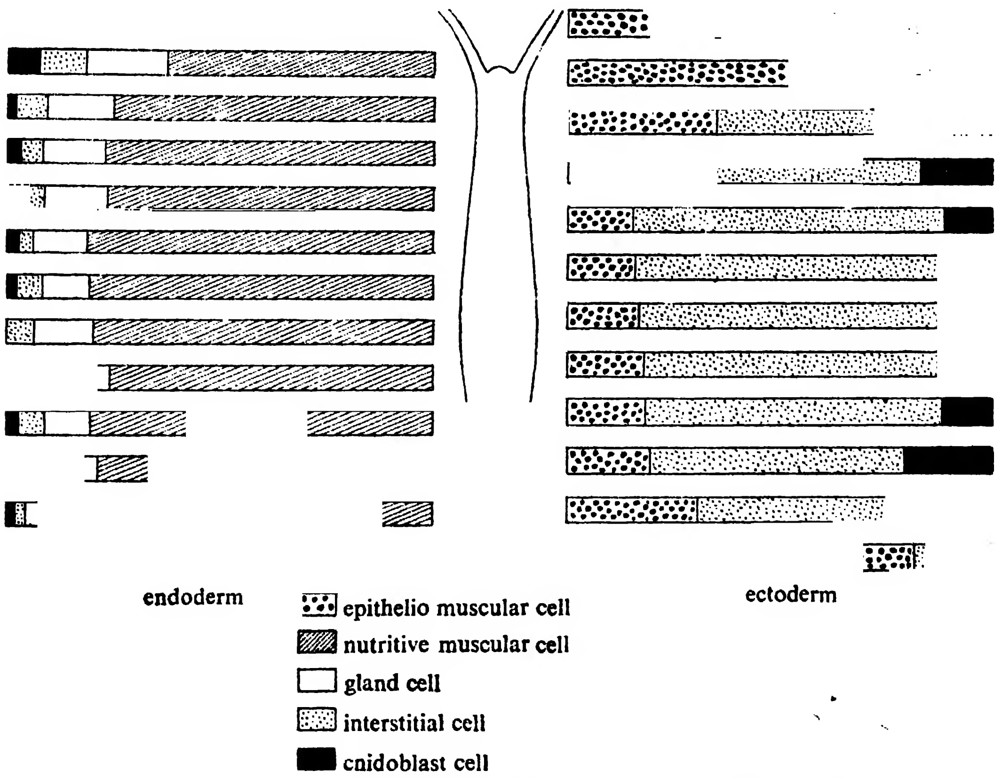


Fig. 11.8. Relative distribution of principal cell-types along the antero-posterior axis of *Hydra*, (after Mookerjee, Sanyal, Sinha).

middle piece material at the base of any one of the tentacles. When the host Hydra is cultured, the induced basal disc at the subhypostomal region gradually descends down and merges with the original host basal disc. While the induced basal disc at the base of the tentacle ascends up to the tip of the tentacle and is discharged through the tentacular tip. These experiments demonstrate the existence of two directional cell flow from the subhypostomal region of Hydra. By this cell flow Hydra not only replaces the old cniodoblasts but also renews the entire cell column. The body of Hydra thus shows a dynamic state and such phenomenon of cell replacement has enabled this animal to be '*immortal*'.

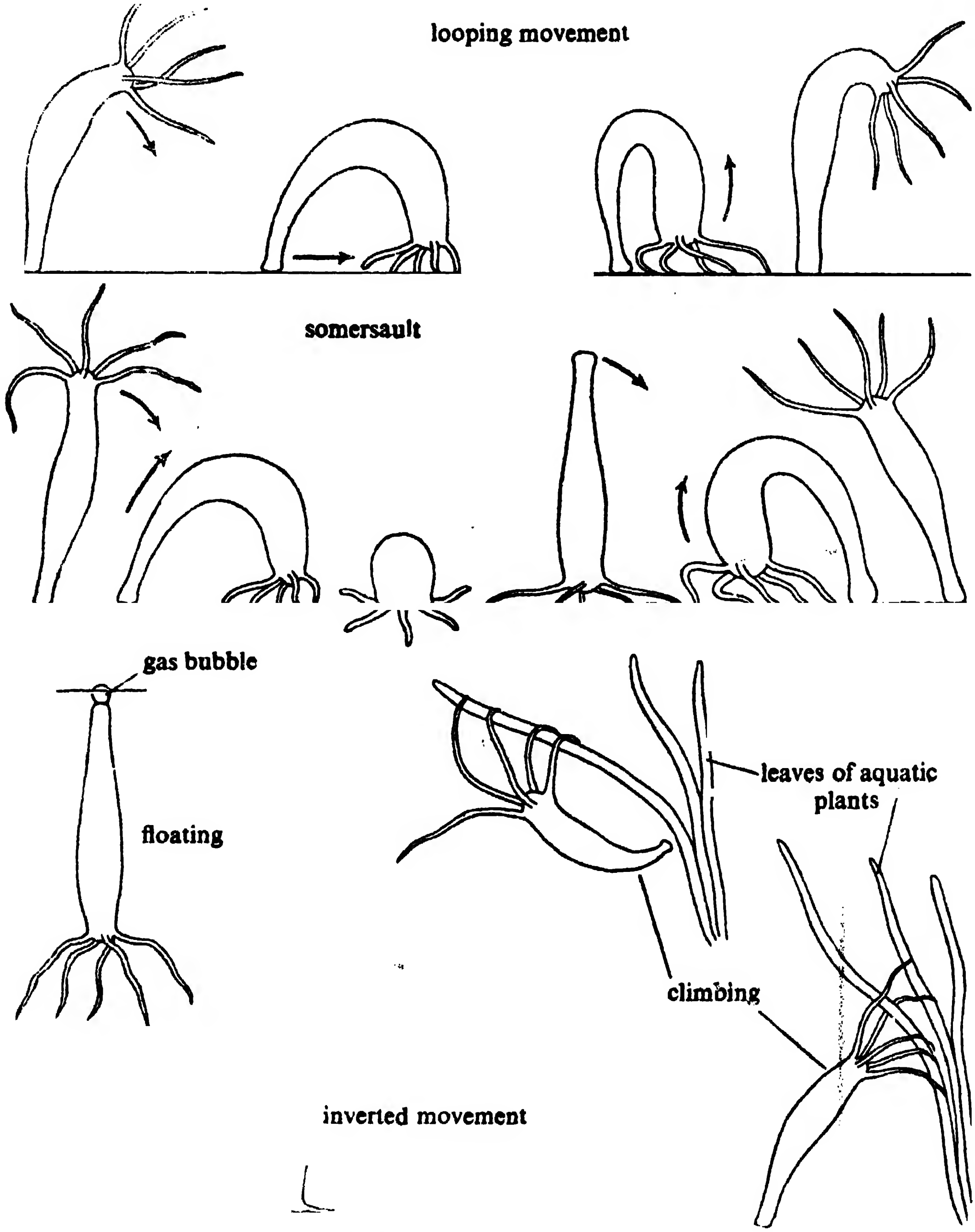


Fig. 11.9. Locomotion in *Hydra*. Arrows indicate the direction of body movement.

LOCOMOTION. Hydra normally remains attached to the substratum by basal disc and stands erect. For capturing the prey and to change the location, Hydra exhibits several types of movement (Fig. 11.9).

Looping. While standing erect the animal bends its body and fixes the tentacles to the substratum by the glutinant nematocysts. It then releases the attachment of the basal disc and moves its free end to a new site. The animal now stands up by disengaging its tentacles.

Somersaulting. In this type of movement, Hydra fixes itself on the substratum by the hypostomal end and shifts the attachment of basal disc. The basal disc is then rotated 180° and is fixed at a new point. The hypostome is again raised.

Other types of movements. Hydra often uses its tentacles as legs and moves in an inverted way. Occasionally, Hydra may glide along the substratum by the pseudopodial action of the basal disc cells. Sometimes, Hydra can produce a bubble of gas, secreted by the basal disc cells which helps the animal to float on the surface of the water and is passively carried from one place to another by water current or wind flow. Hydra can climb by attaching its tentacles to some distant object and then releasing the basal disc and by contracting the tentacles, the body is drawn up to a new position.

NUTRITION. Nutrition in Hydra is holozoic. The entire process may be divided into *ingestion*, *digestion* and *egestion*.

The food of Hydra comprises mainly of minute crustaceans and their larvae. Instances of taking insect larvae and *Tubifex* are also common. When Hydra is hungry, it exhibits a special kind of movement in search of food. It extends its body to its fullest extent and the tentacles are fully stretched in search of food. Whenever wandering forms like *Daphnia* or *Artemia* larvae come in contact with the tentacles, nematocysts are discharged at once. It has been demonstrated that feeding reaction may be induced by the application of glutathione. The penetrant type of nematocysts penetrates the body of the prey to inject the hypnotoxin to cause paralysis and the volvent types wrap the body of the prey. After causing paralysis, the tentacles bend inward and carry the food towards the mouth. The mouth then opens and by muscular contraction it pushes the food into the coelenteron. It is said that the food is then cut into bits by the beating of flagella of the flagellated type of the nutritive-muscular cells.

The gland cells of the endoderm become activated and produce digestive juices containing only proteolytic enzymes. The proteins are broken down into amino-acids which are absorbed by endodermal cells and are then distributed among the body cells. This particular type of digestion is called *extracellular egestion.* The small bits of food matters that escape digestion are engulfed by the pseudopodia of the amoeboid nutritivemuscular cells. In these amoeboid cells the food particles are taken within food vacuoles where the food matters are digested. This type of amoeba-like digestion is called the *intracellular digestion.* In the food vacuole, carbohydrate-splitting, fat-splitting as well as protein-splitting enzymes are produced. Thus in Hydra a combination of both higher (extracellular) and lower (intracellular) types of digestion occur. Indigestible residues are passed out to the exterior through mouth which also acts as an anus.

RESPIRATION AND EXCRETION. Hydra utilises the oxygen dissolved in water for respiration. Oxygen is diffused from the surrounding water directly into the different cells. The carbon dioxide goes out mainly from the ectoderm by diffusion. The nitrogenous waste products are also removed from the body surface through diffusion.

REPRODUCTION. Hydra reproduces asexually as well as sexually.

Asexual reproduction. The asexual reproduction includes **Budding** and **Fission.** Budding is most common and regarded as the normal way of propagation which occurs throughout the season in well-fed mature individuals. A bud appears as a conical protuberance of the body wall from the budding zone. This projection contains ectoderm, mesoglea, endoderm and the continuation of the coelenteron of mother Hydra. Gradually, this projection elongates and attains a considerable length. Rudiments of tentacles appear at the free end of the bud. The hypostome is conical and bears the opening of the mouth at the centre. After this a constriction appears at the region of junction of

the developing bud with the mother's body. Gradually, the constriction becomes deeper. By this time basal disc in the bud is formed. Finally, the bud detaches itself from the body of the mother and leads an independent life (Fig. 11.10).

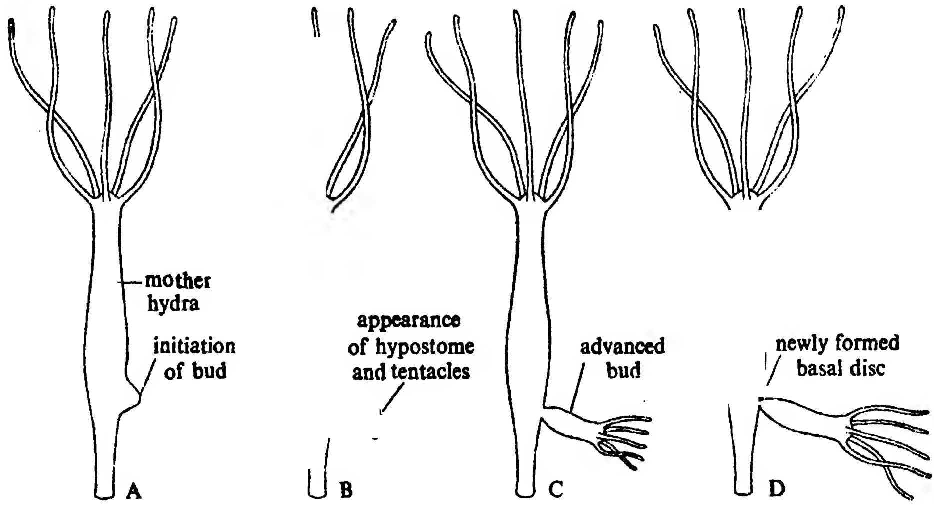


Fig. 11.10. Bud formation in *Hydra*. A. After 3 hours. B. After 24 hours. C. After 48 hours. D. After 72 hours.(courtesy: Dr. R. Palit).

Several buds may occur in a single mother Hydra at a time, although the usual number is one. When several buds are present the older one is located towards the proximal side while the fresh ones are on the distal side.

Both longitudinal and transverse fissions are seen in Hydra. But these fissions generally follow accidental breakdown and are not routine modes of reproduction. In this type of reproduction, the rest of the parts is grown by a process called *regeneration*.

Events of regeneration. Hydra is capable of replacing any of its lost structures within a short time. This power of regeneration is due to highly plastic nature of its cellular organisation. When the hypostome or the basal disc is amputated, the lost strcutures are reformed by the existing mass of cells within 48 hours (Fig. 11.11). The whole phenomenon of restitution may be divided into two phases. At first, the closure of the wound occurs which involves extension of the endoderm cells, migration and secretion of gland cells, formation of a slime plug from the secreted material and ultimately coalescence of the endoderm cells at the centre of the wound. This completes the phase of wound healing and after wound healing, the second phase, i.e., the differentiation of the lost structure takes place. The histodifferentiation of the hypostome starts with the formation of a new layer of ectoderm over the cut surface from the endodermal cells, plastering the open end. Finally, during the reorganisation of the hypostome, the gland cells gradually lose their granules and take up a non-granular amorphous nature. The gland cells and other endodermal cells at the future hypostome site change their shape to crescentic forms. Formation of tentacles is initiated by the extension of the coelenteron at specific sites. When the tentacle grows a good number of cells are seen coming out from the junction of tentacle and the hypostome. The gland cells never enter the tentacle and other endodermal cells undergo vacuolation while entering the tentacular lumen. During tentacle formation a large scale differentiation of nematocysts takes place.

The wound healing phase in the restitution of basal disc is similar to what happens in the case of hypostome regeneration. After the formation of a new layer of ectoderm from endoderm, the delaminated cells become flattened sidewise and assume appreciable tallness. These newly formed columnar cells further take up fibrous nature and spread over the presumptive basal disc area. Almost all of the gland cells including some other

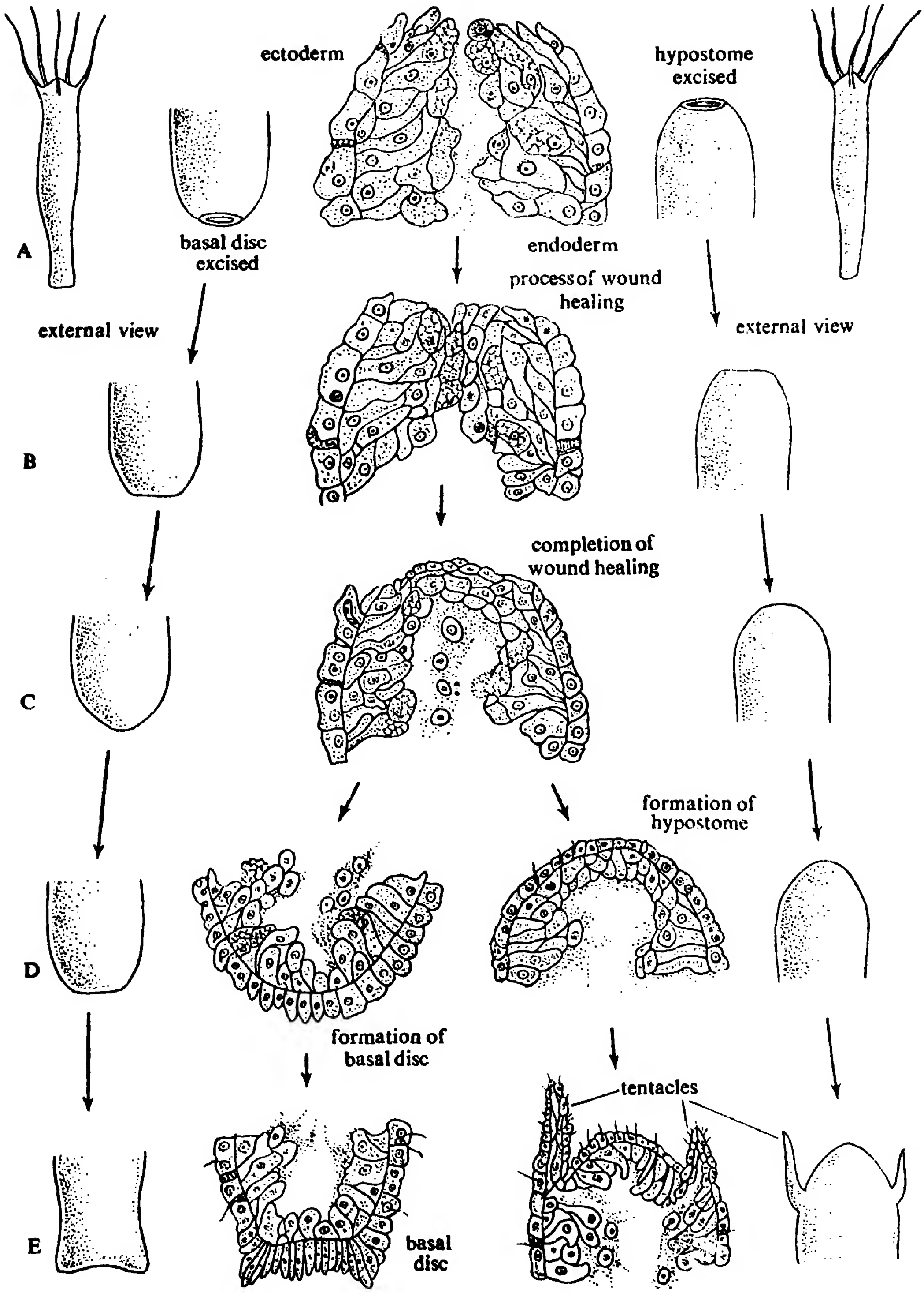


Fig. 11.11. Events during the hypostome and basal disc regeneration of *Hydra*. Note that both in the regeneration of basal disc and hypostome, cellular activities are same up to wound healing stage C. Then the incidents differ at the two sites (D, E). (after Mookerjee and Bhattacharjee, courtsey: Dr. S. Bhattacharjee).

endoderm cells which once migrated to the amputated site are now thrown out and are found in free state inside the coelenteron. The cellular events during hypostomal and basal disc regeneration are shown in Figure 11.11.

Sexual reproduction. Propagation by sexual process is very rare in Hydra. Sexual reproduction does not occur throughout the year, but happens occasionally. Most

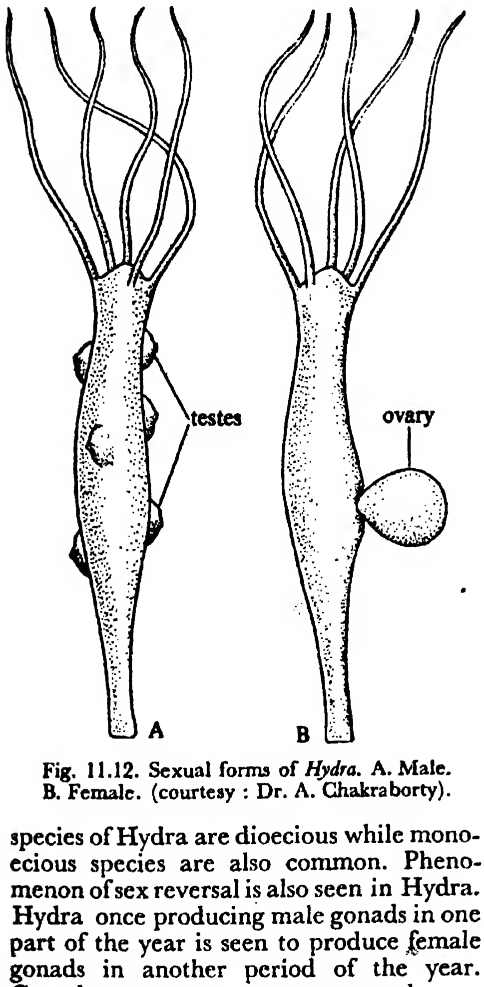


Fig. 11.12. Sexual forms of *Hydra*. A. Male. B. Female. (courtesy : Dr. A. Chakraborty).

species of Hydra are dioecious while monoecious species are also common. Phenomenon of sex reversal is also seen in Hydra. Hydra once producing male gonads in one part of the year is seen to produce female gonads in another period of the year. Gonads are temporary structures and occur in distinct localised zones of the body column. The female gonad (ovary) produces eggs and the male gonad (testis) produces spermatozoa (Fig. 11.12). Both the gonads develop by the modification of the interstitial cells.

Male gonads or testes. Several testes usually occur at the upper half of the body. Each testis is a conical swelling of the ectoderm. It has a heap of rapidly multiplying interstitial cells covered by a protective layer of epitheliomuscular cells. These rapidly multiplying interstitial cells are called the *spermatogonia*. Each spermatogonium divides repeatedly to produce a large number of *spermatocytes* which migrate outwards and become round. Each cell now undergoes two maturation divisions to form four nuclei in an undivided mass of cytoplasm. These are called as the *spermatids* which are transformed into *spermatozoa*. Each spermatozoon has a conical head, short neck and a long wavy tail. When the testis matures the covering capsule ruptures and the spermatozoa are liberated in water where they remain viable for a day or two.

Female gonad or ovary. The development of ovary resembles the formation of testis at the earlier stages. Of the rapidly multiplying interstitial cells, one becomes amoeboid. This is the *oocyte* which increases in size at the expense of the others which provide nutrition for the developing oocyte. The cytoplasm of the oocyte is heavily loaded with dark yolk granules. The oocyte then enters into two maturation divisions to form three small non-functional polar bodies and one mature *ovum* or *egg*.

When the egg becomes mature the capsular wall of the ovary ruptures to form a small opening in the ectoderm for the entry of the sperm and thus the egg is exposed. The ovum secretes a gelatinous substance by which a number of sperms are attracted to it and only one sperm fertilizes the ovum.

LIFE-HISTORY. The egg after fertilization begins to divide. The cleavage is total and equal *blastomeres* are formed. The blastomeres then arrange themselves to form a cellular ball called the *blastula*. The wall of the blastula is composed of a single layer of cells and the enclosed cavity is called the *blastocoel*. New cells are formed and cut off from the inner end of the existing cells and migrate into the blastocoel to form the inner layer. This stage is called the *gastrula*. The outer layer is destined to form the ectoderm and the inner solid layer is converted into the endoderm. The endoderm is solid at first which hollows out subsequently to form the coelenteron. A jelly-like mesoglea is

formed in between the two cellular layers. The embryo now secretes a horny capsule or cyst with spinous outer surface. The embryo then drops away from the mother's body and sinks to the bottom of the pond. After some time (the period varies from about 10 to 70 days) the capsule softens and a young Hydra with small tentacles hatches out. This young Hydra now settles down and begins to feed and grow (Fig. 11.13).

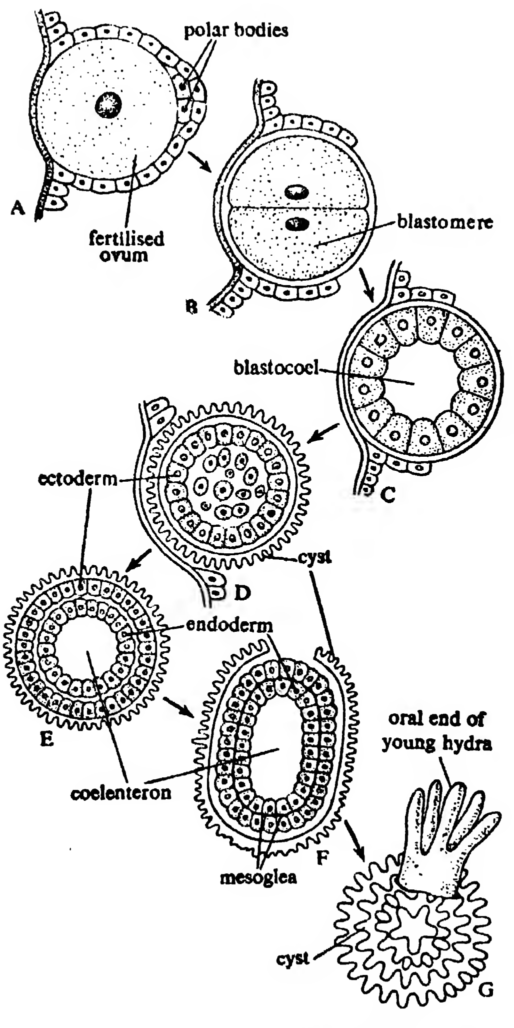


Fig. 11.13. Developmental stages of *Hydra*. A to F. Sectional view. G. External view.

A. Fertilized ovum. B. 2-celled stage. C. Blastula stage. D. Beginning of gastrulation. E. Late gastrula. F. Fully formed young. G. Hatching.

Thus, the development of Hydra is direct and a larval form which is the characteristic of other cnidarians is absent.

Example of the Phylum Cnidaria—*OBELIA*

HABIT AND HABITAT. *Obelia* is a typical representative of colonial hydrozoa (Fig. 11.14). It is exclusively marine. It exists in two principal forms, the polyp and the medusa. The polyp or hydroid form

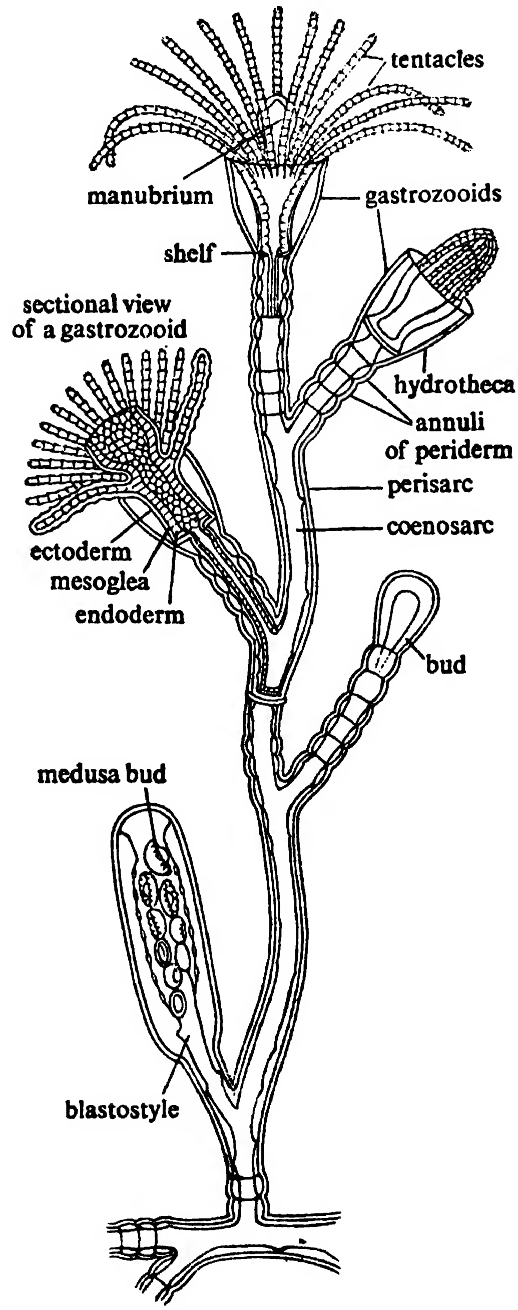


Fig. 11.14. Enlarged view of an *Obelia* colony. (after Parker and Haswell).

represents the asexual phase of its life-history and the medusoid form represents the sexual phase. There is an alternation of these two phases or generations in its life-cycle. Thus it shows a typical instance of *Metagenesis*.

I. Hydroid or Polyp phase

Hydroid stage of Obelia is a colonial form. It is a branched filament-like structure and remains attached with the substratum. The colony is polymorphic, i.e., a number of individuals or zooids are present which are morphologically as well as functionally different from each other.

A. **Hydrorhiza and Hydrocaulus.** Obelia colony is constituted of two portions —the horizontal portion is called the *Hydrorhiza* and the vertical portion bearing the zooids is named as the *Hydrocaulus*. Hydrorhiza is a branched structure and gives only mechanical anchorage to the whole colony. From the hydrorhiza arises the vertical hydrocaulus having short lateral alternate branches bearing zooid at the terminal ends. Two types of zooids are seen —*Gastrozooids* having nutritive function and *Blastostyles* for reproduction. In addition to the fully-formed gastrozooids and blastostyles, the lateral branches bear short club-like structures which are either primordial or developing gastrozooids or blastostyles. Both the hydrorhiza and the hydrocaulus are hollow tubes called the *coenosarc*, covered externally with *perisarc*. Coenosarc is made up of two cellular layers, the outer one is designated as ectoderm and the inner layer is called endoderm. In between these two cellular layers there is a thin non-cellular *mesoglea* or *mesolamella*. Coenosarc contains a tubular cavity known as *coelenteron* which is continuous throughout the colony and is filled with a fluid. Histological picture of the cellular layers resembles more or less to that of Hydra. Obelia possesses one kind of nematocyst called the *basitrichous isorhizas*. The capsule is oval, the thread tube is open at the tip with spines at the base only. The tentacles of Obelia are solid and contain a core of endoderm cells. The perisarc or periderm is a cuticle-like transparent non-cellular layer secreted by the ectoderm of coenosarc. Perisarc is separated from the coenosarc and at places it shows attachment with the coenosarc and thus showing some constrictions which are known as annuli of perisarc or periderm.

B. **Gastrozooid or Trophozooid or Nutritive Zooid.** Most of the zooids present in the hydroid stage of Obelia are the gastrozooids (Fig. 11.15A). They are specially designated to perform nutritive function and feed the whole colony. Each gastrozooid has a short tube-like body having at its distal end a conical projection called *hypostome* or *manubrium*. The mouth is situated at the terminal end of the manubrium. Surrounding the manubrium there is a circlet of about twenty four solid tentacles. This zooid is enveloped by a base-like investment called *hydrotheca*. Hydrotheca is formed by the modification of the perisarc and is perfectly transparent. It is provided with a circular shelf at its proximal end upon which the whole zooid rests. The circular shelf has a central aperture through which the tubular body of the zooid remains continuous with the rest of the colony.

C. **Blastostyle or Gonozooid or Reproductive Zooid.** These particular types of the zooids are few in number in comparison to the number of gastrozooids. Each blastostyle has a long cylindrical body without mouth and tentacles (Fig. 11.15B). The coelenteron is greatly reduced. It is enclosed by a transparent covering called *gonotheca*, a modified form of perisarc. The lateral wall of the body gives off small lateral buds called the *medusa-buds*. They exhibit great structural variations depending upon the developmental sequences. When the medusa-buds become mature the gonotheca ruptures and thus allows the medusa-buds to escape.

II. Medusoid phase

Medusa develops as hollow offshoot of the blastostyle. When fully-formed, it assumes the appearance of an umbrella with a convex surface by which the medusa was attached with the blastostyle (Fig. 11.15C). This convex side is called the *exumbrella* and the concave side of the umbrella is known as the *subumbrella*. From the centre of the subumbrellar surface emerges a hanging tube called manubrium bearing a square mouth at its terminal end (Fig. 11.15D). The edge of the umbrella gives rise to a very short circular shelf called *velum*. At the junction of the exumbrellar side and velum there is a circlet of tentacles. The number of

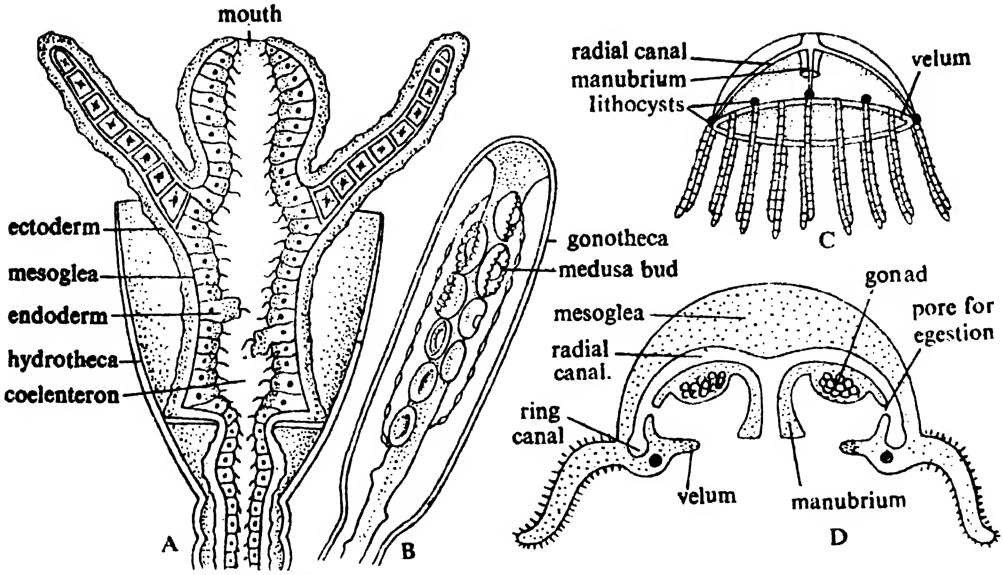


Fig. 11.15. Enlarged view of certain zooids of *Obelia* colony. (after various sources). A. Gastrozooid. B. Blastostyle. C. Medusa. D. Sectional view of medusa.

tentacles is sixteen in a newly-formed stage but the number may increase with age. At the bases of alternate tentacles there lies a sense organ in the form of *lithocyst* or marginal sense organ. Each lithocyst has a very small spherical sac-like body that encloses a central calcareous mass and sensory cells. These sense organs regulate and co-ordinate the movement of the organism.

The mouth leads into the coelenteron lodged inside the manubrium. From the base of the coelenteron emerges four equidistant radial canals, which ultimately open into a ring canal situated at the margin of the body of the umbrella. Through these canals food matters are conveyed to the different parts of the body.

The histological structure of the medusa is same as that in the hydroid stage. Mesoglea is thick and often contains wandering cells and fibres. The only peculiarity is the velum which lacks the endoderm. The two sides are composed of ectoderm with a median layer of mesoglea. In the margins of both the exumbrella and subumbrella, the ectoderm contains nerve cells. In exumbrella, the nerve cells crowd together to form an outer ring and in subumbrella it constitutes an inner margin.

The whole organisation of the body of the medusa exhibits distinct radial symmetry. The medusae are unisexual (dioecious). Gonads are ectodermal in origin and remain in close association with the radial canals towards the subumbrellar surface. They are round in appearance and are four in number. Both the male and female gonads are similar externally.

Life-history. The male gametes or spermatozoa, after maturation, are liberated into water and one spermatozoon fertilizes a female gamete or ovum and thus results into the formation of a zygote. The single-celled zygote divides repeatedly and the daughter cells reorganise to form stages like blastula and gastrula in due course. Finally, a larval form—the *planula* larva is produced.

Planula larva. The planula larva has an elongated and ovoid appearance. The outer layer of the body is composed of ciliated ectodermal cells and the inner layer is the endoderm. Mouth is absent. It is free-swimming and contains a cavity which is the primordial coelenteron. After a very brief free-swimming existence, the palnula larve settles down and fixes itself to the substratum by one pole and transforms into the next stage—the *hydrula* stage.

Hydrula stage. The fixed end of this form is designated as the aboral end and the free or oral end develops a manubrium and a circlet of tentacles. Then a mouth is formed at the centre of the manubrium. The hydrula, thus formed, gives out lateral buds and transforms into an Obelia colony

and thus exhibits a typical instance of metagenesis.

METAGENESIS IN OBELIA. Amongst Cnidarians, Obelia shows excellent metagenesis. The Obelia colony represents the hydroid or asexual stage, which produces medusa-buds by budding (Fig. 11.16).

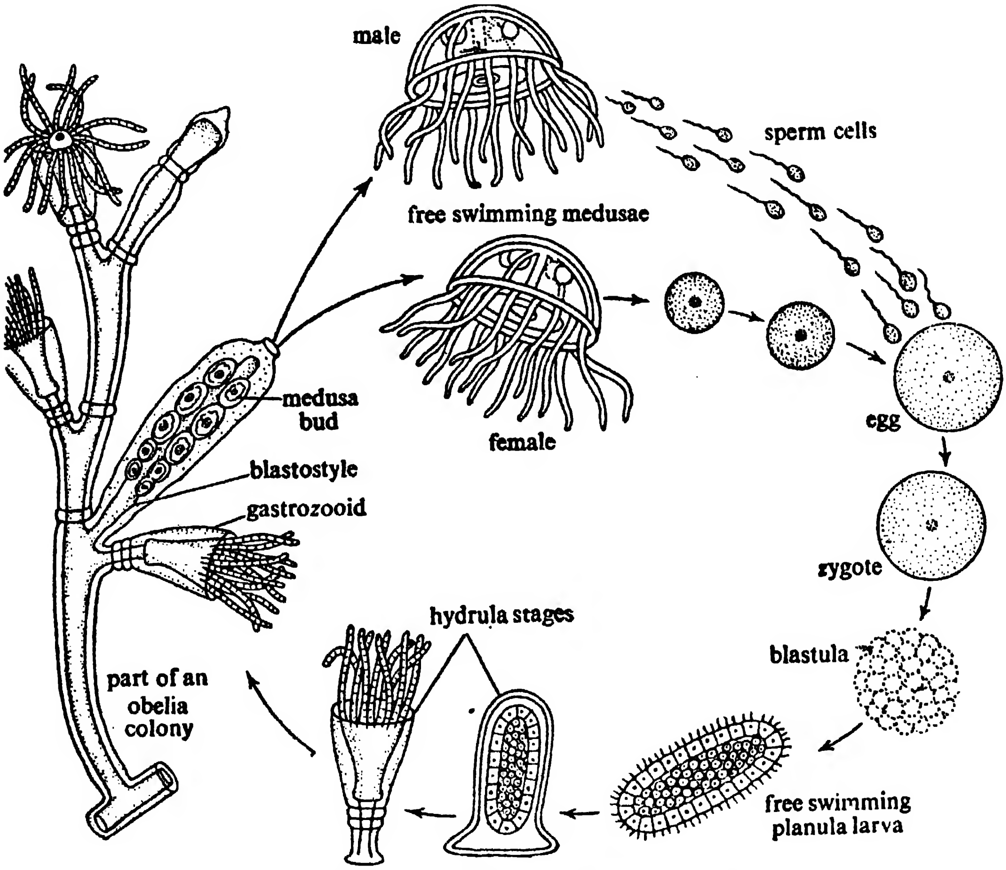


Fig. 11.16. Life-history of *Obelia*. Note the presence of asexual and sexual phase in the life-history. The free-swimming medusae and planula larva assist in the dispersal.

These medusa-buds subsequently transform into full-fledged medusae. The medusae represent the sexual stage and possess male or female gonads. The male and the female gametes are produced in the respective gonads. Mature male and female gametes unite and result into the formation of a zygote, which in turn passes through the usual developmental stages. The developmental process in Obelia is indirect and intervened by the presence of larval forms, which gives rise to the Obelia colony. So in the life-cycle of Obelia there is a distinct alternation of two generations Fig. 11.17). Such a phenomenon is ed *metagenesis*.

EXAMPLE OF THE PHYLUM CNIDARIA—*AURELIA*

Class Scyphozoa includes a variety of species. The shape of the body in almost all the forms varies greatly. The species discussed here is known as *Aurelia aurita* which is popularly known as moon jelly.

STRUCTURE. Adult Aurelia represents medusoid stage. It has the typical form of a medusa (Fig. 11.18). But the concave and convex sides of the umbrella are more pronounced. The edge of the umbrella is provided with a number of small tentacles. The outline of the umbrella is not smooth but is curved into eight equidistant notches within which sense organs are located. Each notch is provided with a pair of marginal lappets.

Velarium. The true velum as seen in Obelia medusa is absent. The edge of the umbrella of the Aurelia is very delicate and flexible due to subumbrellar extension called the *velarium*, which is analogous to

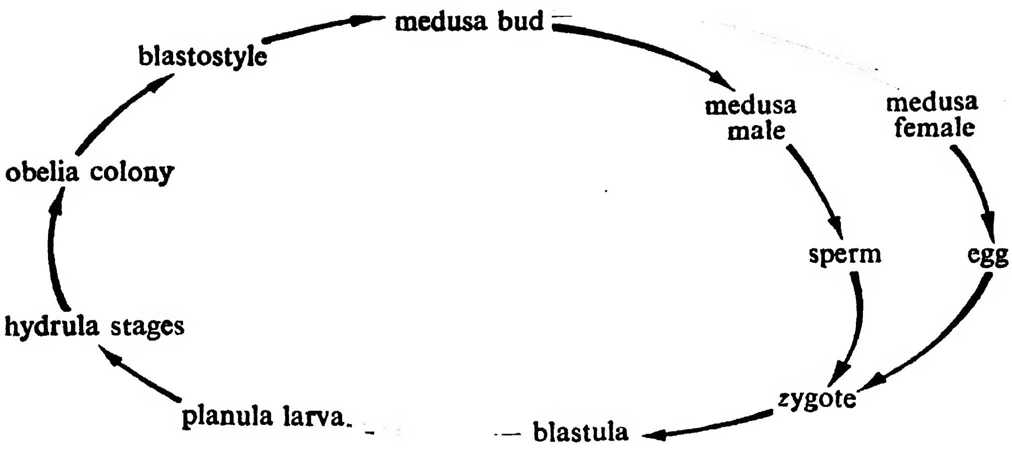


Fig. 11.17. Life-cycle of *Obelia*.

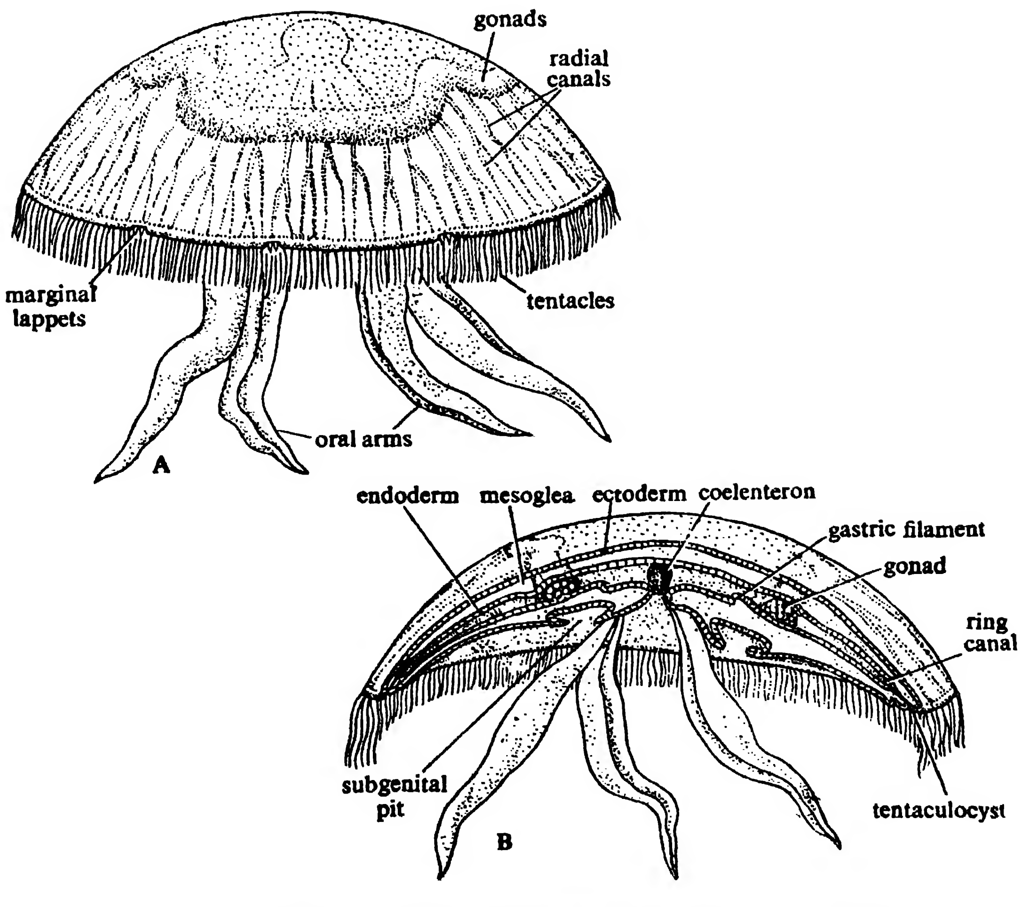


Fig. 11.18. Figures show the lateral view (A) and sectional view (B) of *Aurelia*.

the velum of Obelia and contains endodermal cavity.

Mouth. Mouth is distinctly four-cornered and is borne at the tip of a short manubrium (Fig. 11.19B). The corners of

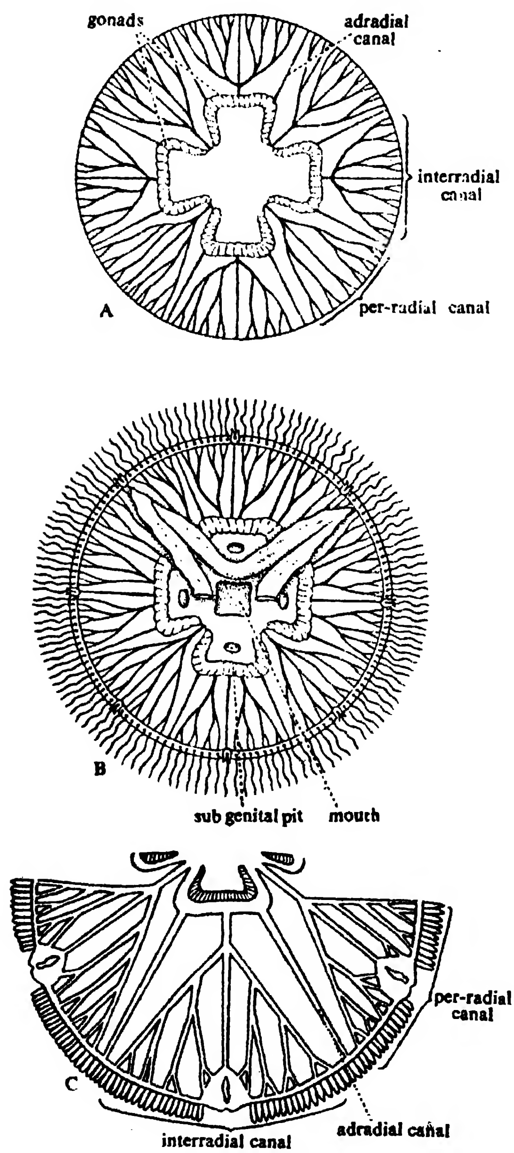


Fig. 11.19. Various structures from the dorsal (A) and ventral (B) sides of *Aurelia*. Two oral arms have been excised in figure B. Figure C shows a diagrammatic representation of the arrangement of various canals in a part of *Aurelia*.

the mouth are drawn out into four lobes called oral arms which are beset with batteries of nematocysts. Each oral arm is infringed with small lobules at its margin and possesses a median groove.

Subgenital pits. On the subumbrellar surface, between the manubrium and the bell margin and along the inter-radial planes of the body, there are four small depressions called subgenital pits. Though they are placed immediately beneath the gonads, yet the subgenital pits have no connection with them.

Coelenteron. Mouth leads into a short tube (gullet) which opens into a centrally located stomach. Stomach is produced into four inter-radial gastric pouches extending upto the half-way between the centre and the edge of the umbrella. Numerous small gastric tentacles are present on the floor of the gastric pouches. The gastric tentacles are composed of endoderm with a central core of mesoglea. Numerous nematocysts are also present in the gastric tentacles. The function of these structures is to kill the prey if they are taken in the stomach alive. From the periphery of the stomach as well as from the gastric pouches, sixteen radial canals originate of which four are perradials, four inter-radials and eight adradials (Fig. 11.19C). Both perradials and inter-radials are branched but the adradials are unbranched. All the radial canals ultimately open into a ring or circular canal situated at the margin of the body.

Gonads. A medusa is unisexual and the gonads are exclusively endodermal in origin. Gonads are four in number, coloured and horse-shoe shaped bodies, situated at the floor of the gastric pouches.

Sense organ. The sense organs are known as *tentaculocysts* or *rhopalia*, which are eight in number (Fig. 11.20). Each tentaculocyst is a modified tentacle. It is kept hidden by marginal lappets and by a hood-like process on the outer side. Each tentaculocyst is a hollow tube having connection with the ring canal. At the tip of this tube there is an aggregation of calcareous particles (statocyst) derived from the endoderm. The ectoderm on the outer side of it gives rise to an ocellus. Another endodermal ocellus associated with the statocyst is present. Two cavities are present in a tentaculocyst, one in the exumbrellar side and the other is internally placed. These cavities are designated as the olfactory pits and are lined by sensory epithelium. Tentaculocysts regulate and co-ordinate the movement of the umbrella.

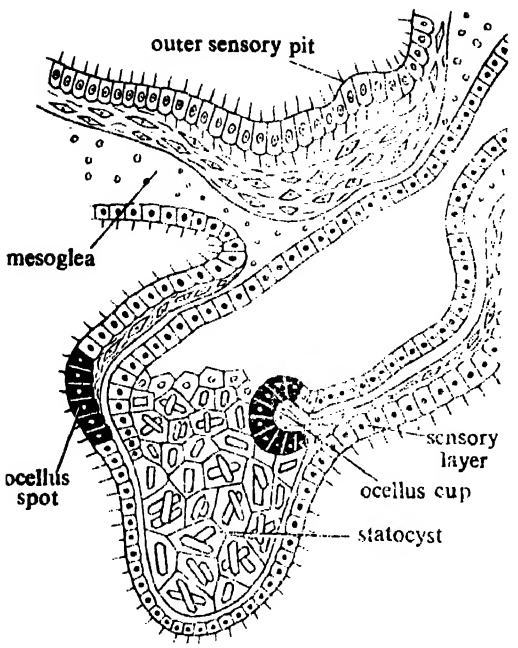


Fig. 11.20. Sectional view of a tentaculocyst or rhopalium of *Aurelia*. (after Kaestner).

HISTOLOGY. Histology of the scyphozoan medusa has the same organisation as that of hydrozoan medusa. The main difference lies in the structure of the mesoglea which contains fibres and loose amoeboid cells. The muscular system is well developed. The broad circular muscle band on the subumbrellar surface is very strongly built and is known as *coronal muscle*. Coronal muscle helps the animal to swim. The nervous system has the general arrangement of the hydrozoan medusa but the marginal nerve ring is either lacking or feebly developed.

LIFE-HISTORY. The sexes are separate. The unisexual medusae do not exhibit any external difference in their appearance. The male medusa produces many sperms which pass out into the surrounding water through the mouth. The sperms swim in water and find their way into the enteron of the female to fertilize the eggs produced in her ovaries. The fertilization is thus internal. The fertilized egg or zygote, through repeated divisions, attains a stage called *morula*. Morula becomes spherical and fluid accumulates in the inner cavity. The outer wall of this stage (*blastula*) is made up of one layer of cells (Fig. 11.21). An invagination from one end obliterates the cavity of the blastula and a new cavity is formed within the layer of cells. The new cavity opens to the exterior through a small opening. This stage is called *gastrula*. The gastrula transforms into a hollow two-layered *planula* larva.

The transformation of zygote into the Planula larva in *Aurelia* is peculiar. The zygotes emerge to lodge themselves on the oral arms of the female medusa. Each developing embryo forms deep spherical pit in the endoderm of gastrodermis in which each embryo develops into a ciliated *Planula larva*. The transformation of a zygote into a planula larva takes two days in Aurelia.

The basic pattern of the planula larva is same as in Obelia except that the blastopore is not completely closed and is represented by a mere slit. The planula larva after a very brief period of free existence, fastens itself to the sea bottom by one pole and loses its cilia and metamorphoses into a stage called *hydratuba*.

Structure of Hydratuba and Scyphistoma. These two stages represent the hydroid phase of Aurelia. After fixation of the planula larva, a definite mouth is formed at the free end and it is now called the hydratuba stage. The mouth becomes square and its edge becomes raised into a short manubrium. The aboral portion becomes narrowed into a distinct peduncle. Around the mouth four perradial, four interradial and eight adradial tentacles are developed. Eventually the hydratuba possesses sixteen tentacles. Endoderm forms four longitudinal interradial gastric ridges or *taenioles*. The ectoderm between the mouth and tentacles invaginates to form four interradial depressions known as the *septal funnels* or *infundibula*. The hydratuba remains unchanged for a long time, feeds and produces horizontal branches from which new hydratuba buds off. Finally, the hydratuba becomes segmented by transverse furrows. The hydratuba in this segmented state is known as **Scyphistoma.**

Formation and structure of ephyra larva. The scyphistoma bears a series of transverse constrictions. These constrictions gradually become deeper and as a result the body appears segmented. These segments are ultimately detached from the body column of the scyphistoma and

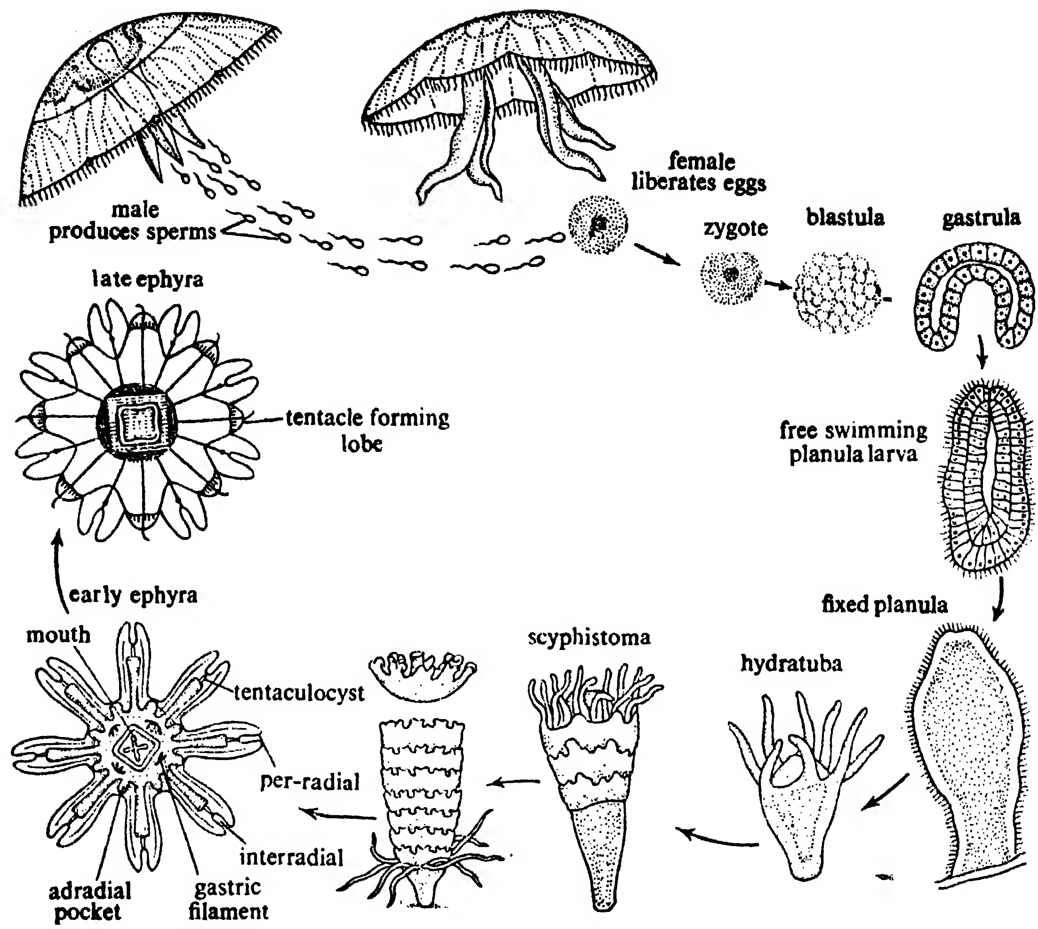


Fig. 11.21. Life-history of *Aurelia*. Note that fertilization is internal and the transformation of the zygote into the Planula larva takes place in special endodermal pit in the oral arm of female medusa. When the Planula larva is fully formed, it comes out of the pit and swims in water. For the sake of convenience the development up to planula has been shown outside the body of the female. The planula larva is peculiar by having a slit-like blastopore.

develop into small saucer-shaped individuals or **Ephyrae.**

Each ephyra larva is characterised by the possession of eight long bifid arms. The concavity at the tip of the arm contains the developing tentaculocyst which is its sense organ. The centre of the subumbrella contains a very short and inconspicuous manubrium. The corners of the mouth are prolonged into four long and frilly oral arms. The original gastric ridges develop into gastric filaments. The original coelenteron shows branching. The region between the arms was initially deeply notched but grows more rapidly and ultimately joins with the tip of the bifid arms to establish regular outer margin. On further metamorphosis, ephyra develops into a full-grown Aurelia.

The process of strobilation of the hydratuba depends largely upon extrinsic factors, particularly on food supply. Sometimes the whole hydratuba may transform into a single adult medusa and under certain conditions ephyra may become again hydratuba.

Metagenesis in Aurelia. The phenomenon of metagenesis is not so well-marked in the life-history of Aurelia (Fig. 11.22). Medusoid generation covers the major and prominent part in its life. The hydroid generation is only represented by the hydratuba and scyphistoma stages. The hydroid generation as such is quite insignificant and may be assigned to be an elaboration of the larval condition.

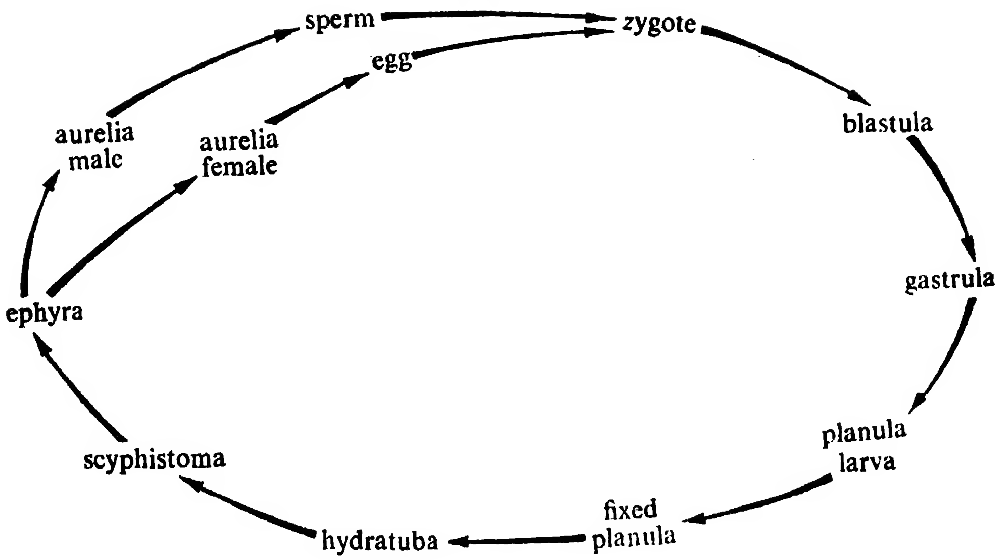


Fig. 11.22. Life cycle of *Aurelia*.

Distinction between Obelia medusa and Aurelia medusa.

The medusae of both Aurelia and Obelia are free-swimming and they exhibit an apparent similarity. In spite of these resemblances, there are various features by which they can be identified. Some of such characters are given in the table Cnidaria-1.

EXAMPLE OF THE PHYLUM CNIDARIA—*SEA ANEMONE*

HABIT AND HABITAT. The sea anemones are found abundantly in the sea shores. They are sessile animals and remain attached with rocks, sea-weeds, molluscan shells or any other solid substratum. The metagenesis or alternation of generation, so common in other classes of Cnidarians, is completely absent in case of the sea anemones. They are represented only by hydroid or polyp stage and the medusoid generation is absent. Most of the sea anemones are brightly coloured. When touched the animal contracts its body immediately (Fig. 11.23). The example discussed here is known as *Urticina*.

STRUCTURE. *Urticina* has a cylindrical body which remains attached to the substratum by its aboral end (Fig. 11.24A). The aboral end is closed and forms a broad sole-like *base* or *pedal disc*. Rows of adhesive warts are present on the surface of the upright *column*. The free end of the body possesses a horizontal plate known as the *peristome* or *oral disc*, ventral to which lies an elongated slit-like opening, the *mouth*. Between the mouth and disc there are eighty short hollow conical tentacles arranged in five circlets. On the body wall small openings known as *cinclides* are present.

Urticina exhibits both bilateral as well as radial symmetry.

NUTRITION. Mouth leads into a flattened cylindrical *gullet* whose terminal edge at each end produces a descending lappet. Two longitudinal grooves are present on the stomodaeum known as the *siphonoglyphs*. Between the gullet and the body wall there are radiating partitions called the mesenteries or septa (Fig. 11.24 B & C). Mesenteries are of three types :

1. Primary mesenteries—when the partitions are complete. At each end of the gullet two such mesenteries are present. They are called the directive mesenteries.
2. Secondary mesenteries—when the partitions are incomplete and run half way between the gullet and the body wall.
3. Tertiary mesenteries are just small ridges on the inner wall of the body.

The gullet opens into the *stomach* which gives off a number of intermesenteric chambers. Intermesenteric chambers are in communication with one another by two apertures on each mesentery known as

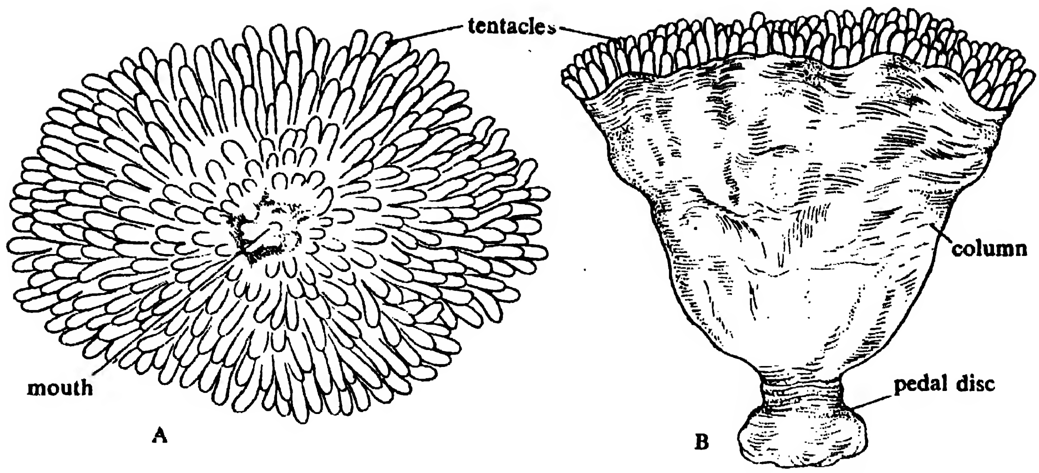


Fig. 11.23. A common sea-anemone of Indian sea shore. A. View from the top and B. Side view (contracted state).

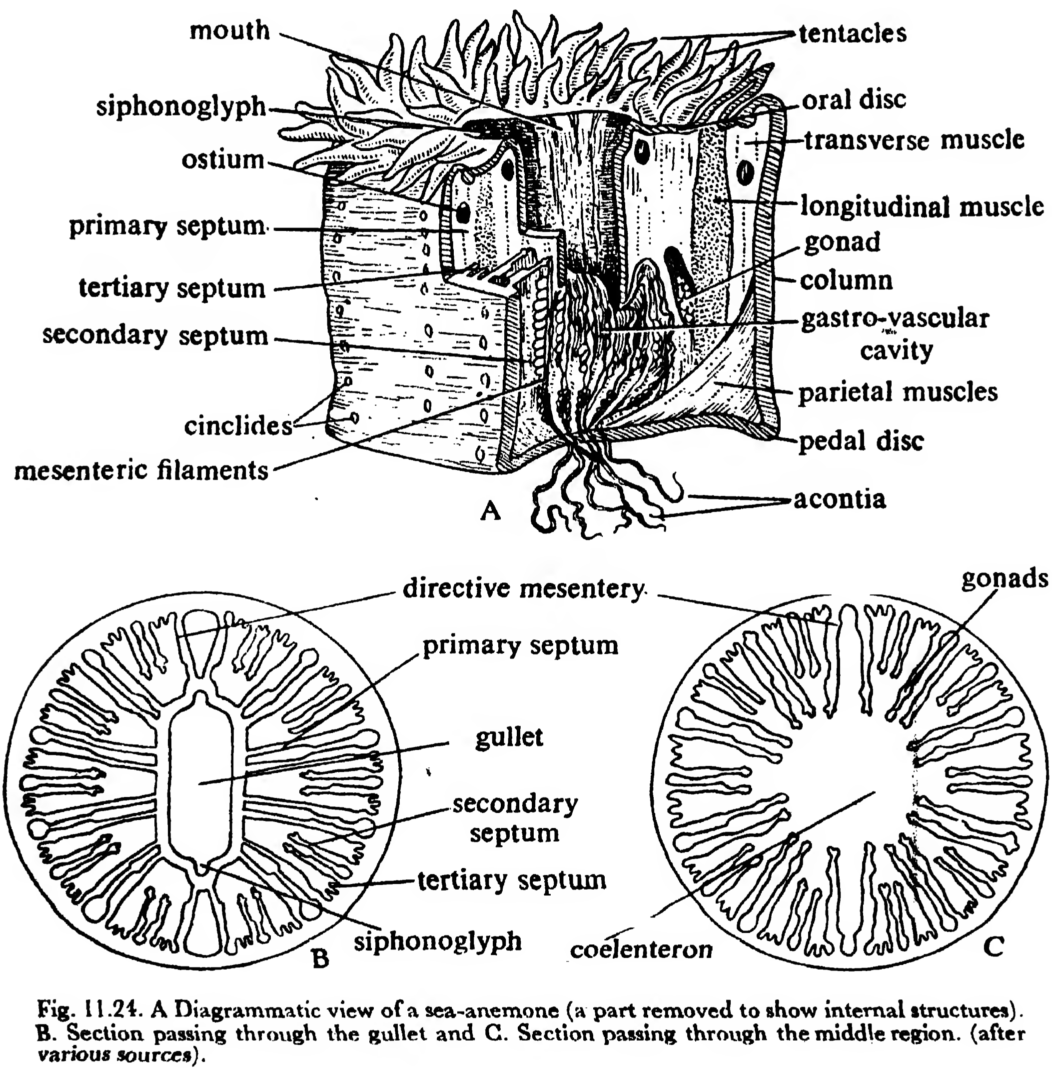


Fig. 11.24. A Diagrammatic view of a sea-anemone (a part removed to show internal structures). B. Section passing through the gullet and C. Section passing through the middle region. (after *various sources*).

TABLE 1—CNIDARIA

COMPARATIVE ACCOUNT OF THE MEDUSOID STAGES OF *OBELIA* AND *AURELIA*

CHARACTERS	OBELIA	AURELIA
1. Edge of the umbrella	Smooth.	Not smooth, provided with eight equidistant marginal notches.
2. Number of tentacles	Sixteen in a newly formed medusa, but number increases with age.	Numerous.
3. Velum	Present.	Absent as such, but an analogous structure called velarium is present.
4. Gonads	Ectodermal in origin, globular in shape and located on the radial canals.	Endodermal in origin, horse-shoe-shaped, located on the floor of the gastric pouches.
5. Manubrium	Large and conspicuous.	Short and inconspicuous.
6. Oral arms	Absent.	Present and four in number.
7. Subgenital pits	Absent.	Present and four in number.
8. Gastric filaments	Absent.	Present and numerous.
9. Marginal sense organs	Simple, in the form of lithocysts	Complex, in the form of tentaculocysts
10. Stomach	Ill-developed.	Well-developed and spacious.
11. Gastric pouches	Absent.	Present and four in number.
12. Radial canal	Four in number and unbranched.	Sixteen, *simple and mostly* branched.
13. Mesoglea	Jelly-like and non-cellular.	Containing fibres and migrated loose amoeboid cells.
14. Duration of metagenesis	Long.	Short.

the *ostia*. The free end of the mesentery below the gullet gives rise to a twisted cord called *mesenteric filament* which is produced into slender threads known as *acontia*. The acontia are seen to protrude out of the body wall through the *cinclides*.

HISTOLOGY. The body wall is composed of an outer ectoderm and an inner endoderm and in between them lies a thick and tough mesoglea (Fig. 11.25B). The gullet (Fig. 11.25A). Transverse section of the tentacle reveals that both ectoderm as well as endoderm are made up of tall columnar ciliated cells. Mesogleal layer is extremely thick and contains delicate fibres and scattered cells.

Elongated cnidoblasts of several types (Fig. 11.26B, 3–5) occur in the ectoderm of the body and in the mesenteric filaments. Gland cells are also abundant in the ectoderm. Mesenteric filament is a

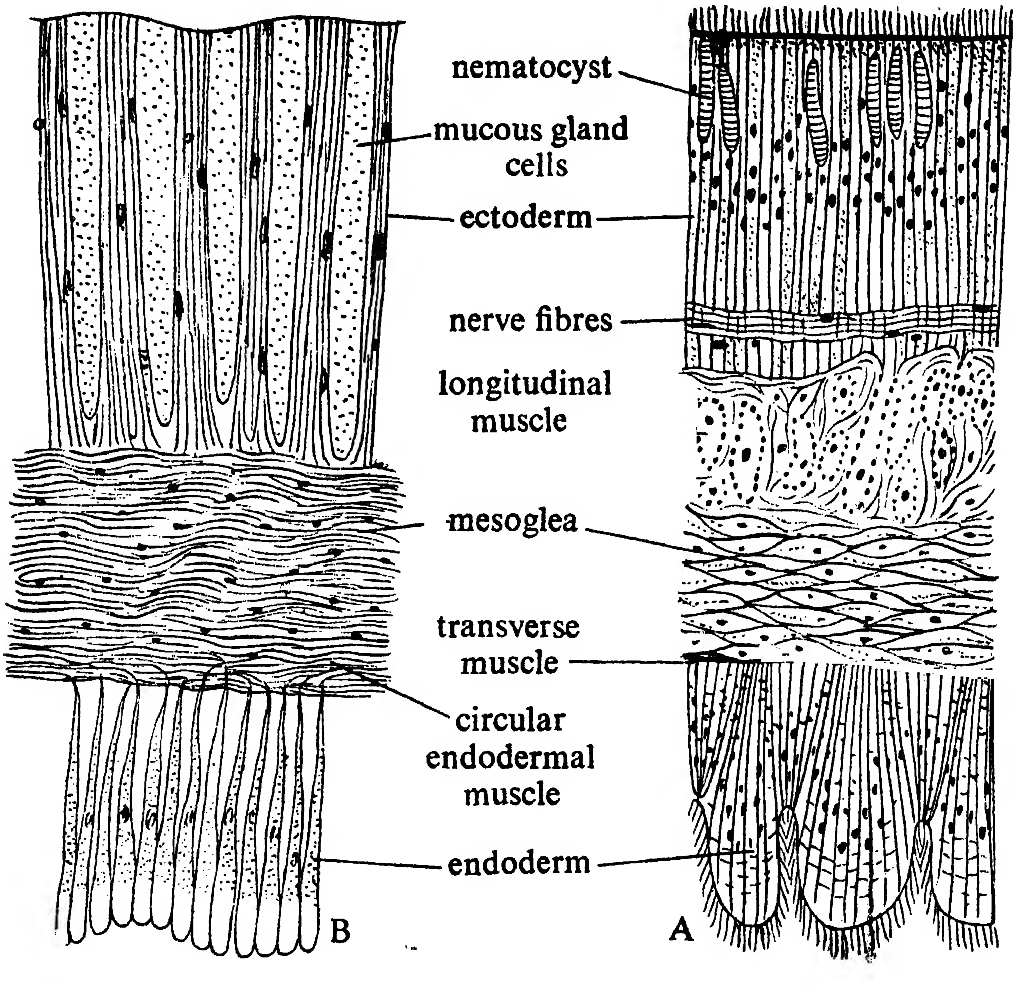


Fig. 11.25. A. Transverse section through tentacle of sea-anemone. B. Transverse section through the body wall of sea-anemone.

has a median mesogleal layer with ectoderm on either side. Mesenteries have a supporting layer of mesoglea with endoderm on two sides. Histological picture is best seen in the section of the tentacle trilobed structure with a glandular median lobe and two ciliated lateral lobes. Cnidoblasts are quite abundant in the mesenteric filaments.

Urticina has well-developed muscles

which are spindle-shaped nucleated fibres. Mesenteries are provided with longitudinal or retractor muscles, transverse muscles and parietal muscles (Fig. 11.26A). The longitudinal muscles are responsible for the contraction of the body and tentacles, while the transverse muscles act in a reverse way. The parietal muscles draw the body to the base, where another set of circular muscles is present to act as sphincter.

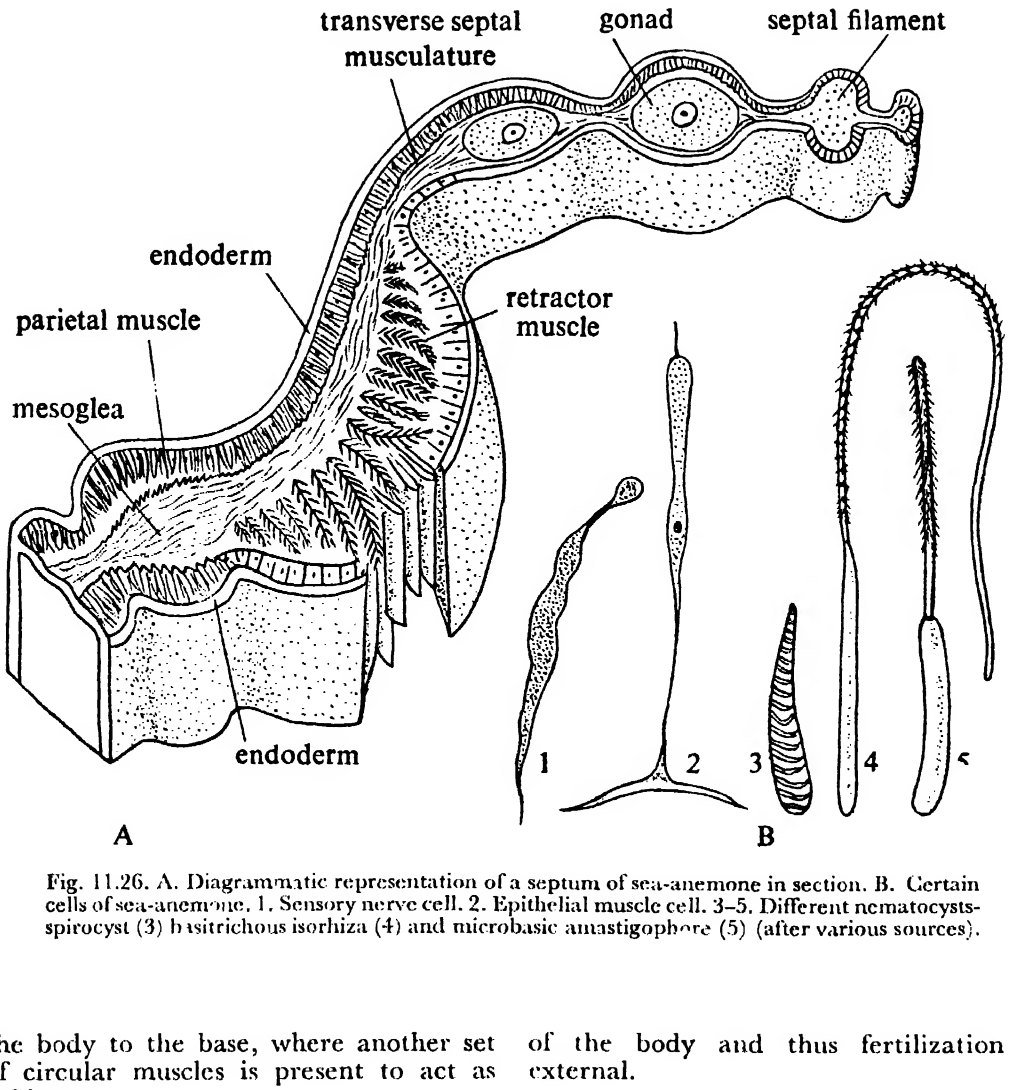


Fig. 11.26. A. Diagrammatic representation of a septum of sea-anemone in section. B. Certain cells of sea-anemone. 1. Sensory nerve cell. 2. Epithelial muscle cell. 3–5. Different nematocysts-spirocyst (3) basitrichous isorhiza (4) and microbasic amastigophore (5) (after various sources).

NERVOUS SYSTEM. Nerve fibres with nerve cells are found in the ectoderm and in the endoderm. Nervous system is simple and essentially a nerve-net type.

REPRODUCTION. Fission or fragmentation may result into the formation of a new polyp. But most common is sexual reproduction. The sexes are separate. The gonads develop in the mesenteries and thus are endodermal in origin. The spermatozoa are discharged to the exterior through mouth and find their way to reach the ovum and eventually fertilization takes place internally and the zygote is formed. In some Anthozoa both the gametes come out of the body and thus fertilization is external.

DEVELOPMENT. The zygote, after passing through the routine stages of development, transforms into a typical Cnidarian Planula larva, which after a brief free swimming existence settles down to metamorphose into an adult. Figure 11.27 illustrates the important features and the plan of life-cycle of a few cnidarians.

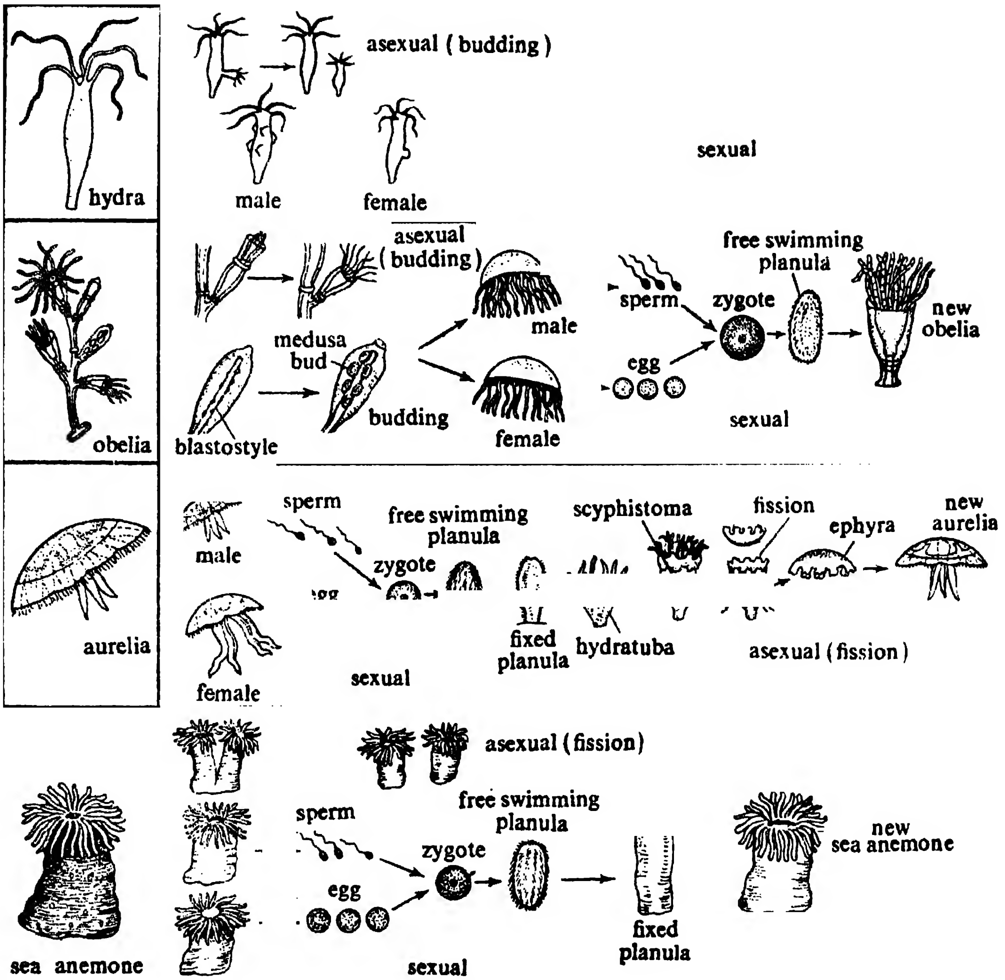


Fig. 11.27. Showing important features in the life-history of a few Cnidarians.

COMPARATIVE ACCOUNT OF THE POLYPOID STAGES OF *AURELIA* AND *URTICINA*

The polyps represent the asexual generation in Cnidarians. The polyps in Cnidarians have similar structural plan and have tube-like appearance with a distinct polar axis. The distal end is marked by the presence of mouth on manubrium and the proximal end is characterised by pedal disc which helps in attachment with the substratum. A number of tentacles encircles the manubrium. In most cases, this basic organisation becomes modified. In *Aurelia*, the asexual generation is very brief and is represented in the life-cycle by the *Scyphistoma*, whereas in *Urticina* (a typical representative of Sea-anemones) the adult itself is a polyp. The medusa is completely absent in Urticina.

The structural organisation of *Urticina* is more complex in nature than the scyphozoan polyp (*Scyphistoma*). The main differences are tabulated below in Table 2—Cnidaria:

TABLE 2—CNIDARIA

CHARACTERS	SCYPHISTOMA STAGE OF AURELIA	URTICINA
1. Shape	Elongated tube-like body with narrow proximal end differentiated into stalk for attachment.	Cylindrical body with a proximal broad base for attachment, an upright column and a distal horizontal disc called peristome.
2. Height	About 1·5 cm. in height.	Diameter of the body may slightly exceed height and is about 7·5 cm. across.
3. Distal tentacles	16 solid tentacles developed in regular order (4 perradial, 4 interradial and 8 adradial tentacles).	Numerous short, hollow and conical tentacles are arranged in 5 circlets.
4. Manubrium	Present.	Absent.
5. Mouth	Square in outline and is placed in the manubrium.	Slit-like—situated in the middle of the peristome.
6. Septal funnels	4 interradial septal funnels are present which sink into gastric ridges.	No such structure is present.
7. Mesenteries	True mesenteries are absent and 4 gastric ridges are present which can be compared with the mesenteries of Urticina.	The stomodaeum and the body wall are connected by numerous radiating partitions called mesenteries. The mesenteries are of three types — primaries, secondaries and tertiaries.
8. Mesenteric filaments	Absent.	The free edge of each mesentery below the gullet produces twisted cord called mesenteric filaments which may in turn produce slender thread-like acontia.
9. Enteric system	Simple in organisation.	Very much complicated and is divisible into stomodaeum, stomach and radially arranged intermesenteric chambers produced by the primary mesenteries.
10. Reproduction	By budding and transverse fission or strobilation.	Develops gonads in the mesenteries and gonads are endodermal in origin.

SOME INTERESTING CNIDARIANS

Protohydra. *Protohydra* (see Fig. 11.29 A) is a peculiar hydra of 3 mm in length. It lacks the usual tentacles. It is available along the shores of Great Britain and northern part of Europe. Protohydra feeds on nematodes and small crustaceans and propagates usually by longitudinal and transverse fission. It is dioecious and lacks a medusaid stage.

Halistemma. *Halistemma* (Fig. 11.28) represents a typical form of Siphonophore colony. Some peculiar features are :

(*i*) Largest nematocyst amongst Cnidarains is present in Halistemma. The length of the nematocyst is about 1–12 mm and the length of the discharged tube is about several millimetres long.

(*ii*) Two alternate rows of the swimming bells are closely pressed together to assume bilateral shape.

(*iii*) When newly formed, the different zooids of the colony are located on one side, but subsequently the stem on which the zooids are borne becomes twisted and appears to be irregular.

Physalia. Another remarkable Siphonophore is *Physalia*, commonly known as Portuguese man-of-war (Fig. 11.28). When touched the long trailing tentacles liberate toxic substances to produce severe pain to other organisms. The noted features are :

(*i*) The size may reach with a float up to 10 to 30 cm in length.

(*ii*) Swimming bells and tentilla are absent.

(*iii*) The gaseous content of the air-sac contains 1·5% Argon, 85 to 91% Nitrogen, and 7·5 to 13·5% Oxygen.

(*iv*) A remarkable instance of commensalism is present between Physalia and the fish, *Nomens*. This small fish swims among the tentacles of Physalia.

(*v*) The float is an elongated bladder-like sac with two pointed ends and ranges from 3 to 12 cm in length.

(*vi*) The female reproductive zooids become detached from the colony as free medusae, but the male ones remain attached.

Porpita. *Porpita* (Fig. 11.28) represents the most modified form amongst the Siphonophores.

Some peculiar features of Porpita are:

(*i*) The float forms a round discoid body with air-chambers. Each of these chambers

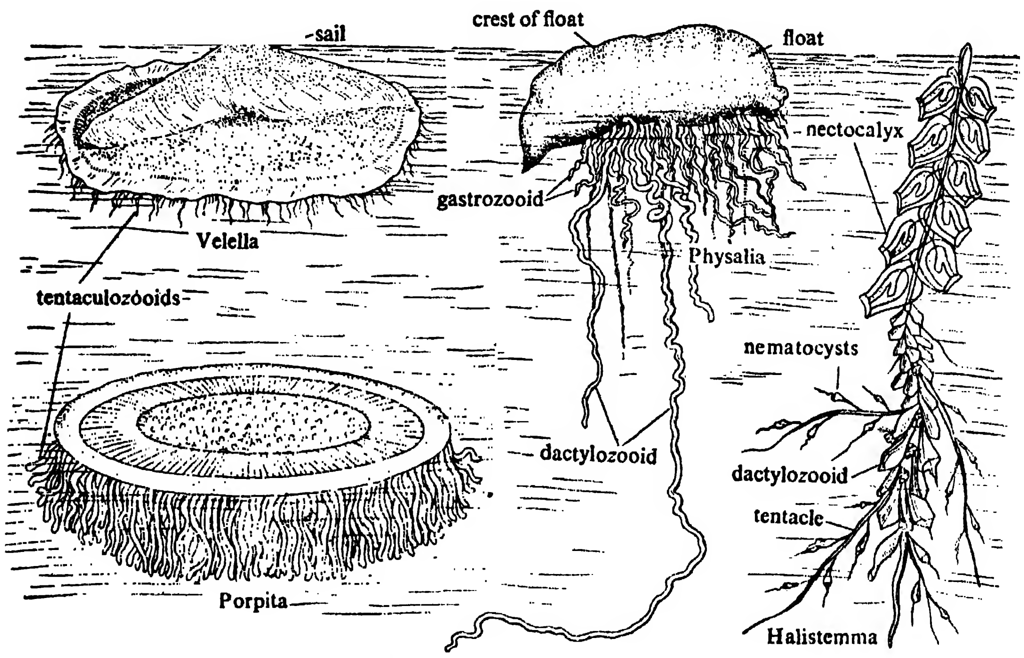


Fig. 11.28. A few representatives of the order Siphonophora.

communicates to the outside by many pores.

(*ii*) The centre of the colony is occupied by a single large gastrozooid.

(*iii*) The edge is provided with simple hollow tentacle-like bodies—the dactylozooids (tentaculozooids).

(*iv*) The gonozooids are like gastrozooids and may possess mouth but tentacle is absent.

(*v*) Beneath the float, there is a mass (so-called liver) permeated with endodermal canals which are regarded to be excretory in function. The walls of these canals are filled with guanine crystals.

Velella. *Velella* (Fig. 11.28) is a closely allied genus of Porpita and it also exhibits a modified form amongst Siphonophora. Both of them belong to the same group and under a single suborder.

Some special features of Velella are:

(*i*) The float is like that of Porpita but it possesses an oblique shell on the upper side and it has rhomboidal form.

(*ii*) The gastrozooid, dactylozooids and gonozooids are all like those of Porpita, but tentilla is absent.

(*iii*) Velella contains 88% water, 5·6% salts, 3% chitin and the rest is covered by other organic substances. Traces of carbohydrate and fat are also recorded.

(*iv*) Just like Porpita, the so-called liver performing excretory function is present.

Diphyes. *Diphyes* represents a peculiar Siphonophore colony, where the float is lacking. The proximal end of the colony is occupied by swimming bells.

The peculiar features are:

(*i*) The swimming bells are two in number and are similar.

(*ii*) The bells are followed by groups of zooids. Each group comprises of a polyp with tentacles, a medusoid form and a large bract encircling them.

CLASSIFICATION

The nature and classification of the Cnidarians had long been a debated issue. The scheme combining Cnidarians and the Ctenophores under one phylum named *Coelenterata* has not been accepted by many authors and in many text-books the Cnidarians and the Ctenophores are regarded as separate phyla.

The scheme of combining the Cnidarians and Ctenophores under a common phylum Coelenterata is not followed nowadays. The Cnidarians are typical diploblastic metazoa of tissue grade of construction while the Ctenophores are triploblastic metazoa. The classificatory scheme presented here is based on the above considerations and both the Cnidarians and Ctenophores have been given the status of separate phyla.

CLASSIFICATION IN OUTLINE

The classificatory scheme followed in the present text is based largely on the plan laid down by L. H. Hyman in her book, "The Invertebrates: Protozoa through Ctenophora (Vol. I)."

PHYLUM CNIDARIA

A. Class **Hydrozoa**

Order 1. *Hydroida.*

Suborder : Anthomedusae (Athecata or Gymnoblastea), e.g. *Bougainvillea, Hydra, Protohydra, Ceratella.*

Suborder : Leptomedusae (Thecaphora or Calyptoblastea), e.g. *Obelia, Clytia.*

Order 2. *Trachylina.*

Suborder : Trachymedusae, e.g. *Petasus, Glossocodon.*

Suborder : Narcomedusae, e.g. *Cunarcha, Polycolpa.*

Order 3. *Milleporina*, e.g. *Millepora.*

Order 4. *Stylasterina*, e.g. *Stylaster, Allopora, Astylus.*

Order 5. *Siphonophora.*

Suborder : Calycophora, e.g. *Praya, Abyla.*

Suborder : Physophorida, e.g. *Physalia, Velella, Porpita.*

B. Class **Scyphozoa**

Order 1. *Lucernariida* or *Stauromedusae*, e.g. *Lucernaria.*

Order 2. *Coronatae*, e.g. *Pericolpa, Nausithoe.*

Order 3. *Cubomedusae* or *Carybdeida*, e.g. *Charybdaea.*

Order 4. *Semaeostomeae*, e.g. *Aurelia.*

Order 5. *Rhizostomeae*, e.g. *Pilema.*

C. Class **Actinozoa** or **Anthozoa**

Subclass Hexacorallia or Zoantharia.

Order 1. *Actiniaria*, e.g. *Urticina, Adamsia, Minyas.*

Order 2. *Madreporaria* e.g. *Madrepora, Astraea, Corallium.*
Order 3. *Zoanthidea*, e.g. *Zoanthus.*
Order 4. *Antipatharia*, e.g. *Antipathes.*
Order 5. *Ceriantharia*, e.g. *Cerianthus.*

Subclass Octocorallia or Alcyonaria.
Order 1. *Stolonifera*, e.g. *Tubipora, Hartea.*
Order 2. *Telestacea*, e.g. *Telesto.*
Order 3. *Alcyonacea*, e.g. *Alcyonium.*
Order 4. *Coenothecalia*, e.g. *Heliopora.*
Order 5. *Gorgonacea*, e.g. *Gorgonia.*
Order 6. *Pennatulacea*, e.g. *Pennatula.*

CLASSIFICATION WITH CHARACTERS

The phylym Cnidaria is a large group and its members possess nematocysts. It is divided into three classes—*Hydrozoa, Scyphozoa* and *Actinozoa.*

Class **Hydrozoa.** The class Hydrozoa (Figs. 11.28 and 11.29) is characterised by the possession of the following characteristic features: Coelenteron (also designated as enteric cavity) is undivided and is without stomodaeum. The individuals are either exclusively polyploid or exclusively medusoid or constituted by both the above forms. Metagenesis is usually distinct. Reproductive cells are usually ectodermal in origin and are discharged to the exterior directly. The mesoglea is non-cellular. The members are mostly marine.

Order *Hydroida.* Polypoid stage is well-represented and the polypoid forms are usually remain fixed. The sense organs are exclusively ectodermal in origin.

Suborder Anthomedusae (Athecata or Gymnoblastea). The gastrozooids lack hydrothecae. The blastostyles are naked. The free medusae are tall and bell-like. The sense organs are in the form of ocelli but are without statocysts. The gonads are borne on the manubrium. Typical examples are : *Sarsia, Corynitis, Steenstrupia, Corymorpha, Tubularia, Clava, Cordylophora.*

Suborder Leptomedusae (Thecaphora or Calyptoblastea). The gastrozooids are provided with hydrothecae. The blastostyles are covered by gonothecae. The free medusae are saucer-shaped. The sense organs are usually in the form of statocysts. The gonads are borne on the radial canals. The examples are: *Laodicea, Staurophora, Obelia, Clytia, Ptychogena, Melicertum, Polyorchis.*

Order *Trachylina.* In this case medusoid generation is well-represented and is with or without polypoid stage. The sense

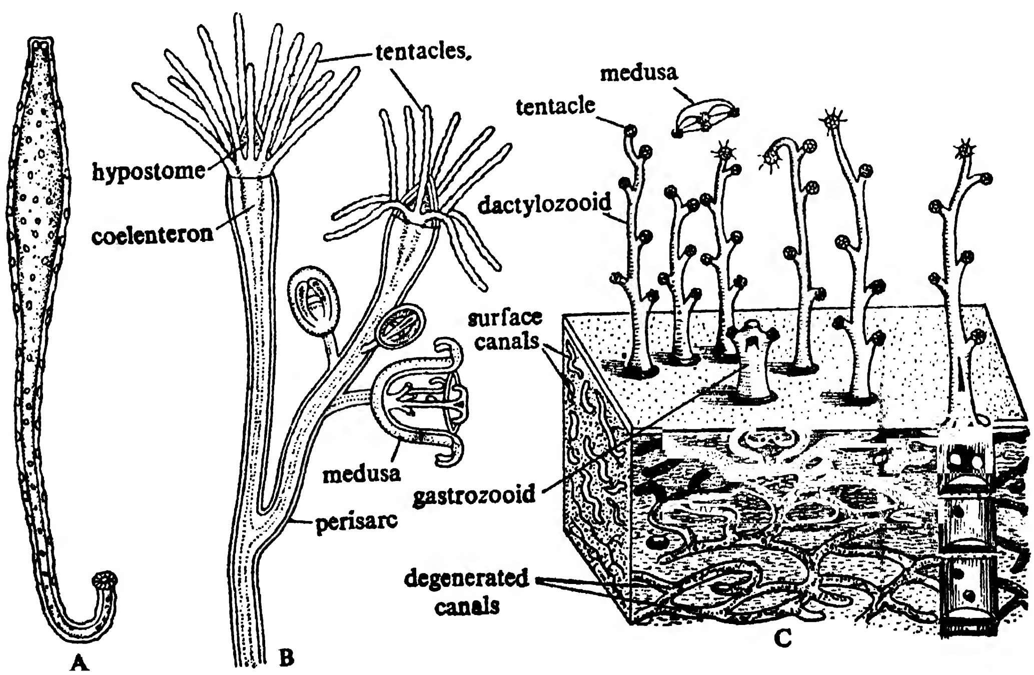


Fig. 11.29. A few representatives of class Hydrozoa. A. *Protohydra.* B. *Bougainvillia.* C. Diagrammatic view of *Millepora.* Showing gastrozooid and dactylozooids (after various sources.).

organs are statocysts or tentaculocysts and consist partly of endoderm.

Suborder Trachymedusae. The margin of the bell is smooth. The gonads are borne on the radial canals. The examples are : *Rhopalonema*, *Aglaura*, *Geryonia*, *Liriope*.

Suborder Narcomedusae. The margin of the bell is scalloped by tentacles. The gonads are present on the floor of stomach or in manubrium. The examples are : *Cunina*, *Cunoctantha*, *Aegina*, *Solmaris*.

Order *Milleporina*. The hydroid stage contains voluminous calcareous external skeleton with gastropores and dactylopores. Through these pores respective zooids protrude. The elongated dactylozooids are hollow and are with capitate tentacles. The medusae may be without mouth, digestive canal and tentacles. The sole representative of the order is *Millepora*.

Order *Stylasterina*. The members of this order are similar to that of Milleporina. The dactylozooids are small, solid and lack tentacles. The gonophores are reduced to sporosacs. The examples are : *Stylaster*, *Allopora*, *Astylus*, *Cryptohelia*, *Distichopora*.

Order *Siphonophora*. They are the colonial forms and exhibit extreme polymorphism of both the polyp and medusa. The polyps lack oral tentacles. The gonophores do not develop into complete medusae. It includes two suborders: *Calycophora* and *Physophorida*.

Suborder Calycophora. The colony is provided with nectocalyces at its upper end. The examples are: *Praya*, *Abyla*.

Suborder Physophorida. The colony contains pneumatophore at the upper end. The examples are *Physalia* (Portuguese man-of-war), *Velella*, *Porpita*.

Class **Scyphozoa.** The adults exist only in medusoid stage and the polypoid generation is very insignificant. The polyp is represented by the *Scyphistoma* and *Hydratuba* The endodermal gastric tentacles are present. The mesoglea is non-cellular but thick. The gonads are endodermal in origin. The velum is absent. The sense organs are usually in the form of *tentaculocysts*.

Order *Lucernariida* or *Stauromedusae*. The umbrella is conical or vase-shaped and remains attached to the substratum by aboral peduncle. The tentaculocysts are usually absent. *Lucernaria* is the typical example.

Order *Coronatae*. The umbrella is free-swimming and is provided with *coronary groove*. The tentaculocysts may vary from four to sixteen in number. The examples are: *Pericolpa*, *Nausithoe*.

Order *Cubomedusae* or *Carybdeida*. The umbrella is cup-like and is four-sided. They are free-swimming forms and four tentaculocysts are present at the perradial plane. The example is : *Charybdaea*.

Order *Semaeostomeae*. The umbrella is disc-shaped and possesses usually eight (four are perradial and four are interradial) tentaculocysts. Four oral arms are present. *Aurelia* is the typical example.

Order *Rhizostomeae*. The original mouth is obliterated due to the fusion of the oral arms. Many small mouths and canals are present in the oral arms. The marginal tentacles are absent. Eight or more tentaculocysts are present. The example of the order is: *Pilema*.

Class **Actinozoa** or **Anthozoa.** They exist only in polyp form. The stomodaeum is strongly developed and possesses siphonoglyphs. Extending between the stomodaeum and the body-wall there are mesenteries. Mesoglea is well-developed with fibrous connective tissue. The gonads are endodermal in origin. The members of this class are exclusively marine.

Subclass Hexacorallia or Zoantharia. They are either solitary or colonial forms. The tentacles and the mesenteries are generally numerous and are in the multiple of five or six. The tentacles are hollow and unbranched. Usually two siphonoglyphs are present. This subclass is divided into five orders. They are :

Order 1. *Actiniaria*. Numerous tentacles and mesenteries are usually present in multiples of six. Skeleton is absent. The examples are the Sea-anemones, such as *Tealia*, *Minyas*, *Urticina*, *Adamsia*, *Edwardsia*.

Order 2. *Madreporaria*. This order includes the stony corals. They are usually colonial forms and possess compact calcareous skeleton. The siphonoglyphs are absent. The examples are *Madrepora*, *Astraea*, *Corallium*.

Order 3. *Zoanthidea*. They are devoid of skeleton and pedal disc. One ventral

siphonoglyph is present. The tentacles are unbranched. The well-known example is : *Zoanthus*.

Order 4. *Antipatharia*. This order includes the black corals. They are colonial forms having comparatively fewer tentacles and mesenteries (6 to 24 in number). The skeleton is in the form of branched chitinoid axis. Two siphonoglyphs are present. The example is *Antipathes*.

Order 5. *Ceriantharia*. Solitary forms with single dorsally placed siphonoglyph. Many tentacles are present and are arranged in two whorls. The mesenteries are all complete. The typical example is: *Pachycerianthus*.

Subclass Octocorallia or Alcyoniaria. The number of tentacles and mesenteries in this subclass are always eight. The mesenteries are complete. The tentacles are pinnately branched. One ventral siphonoglyph is only present. They are colonial forms with endoskeleton. This subclass is divided into six orders.

Order 1. *Stolonifera*. The polyps are not fused and are connected by basal stolons. The stolons are embedded in a basal mat of tissue. The skeleton comprises of separate spicules or the spicules may fuse to form tubes. Example: *Tubipora*.

Order 2. *Telestacea*. The colony consists of very long axial polyps. Many lateral polyps are present at side branches. Example : *Telesto*.

Order 3. *Alcyonacea*. The examples of this order are the soft corals typified by "Dead-men's fingers", *Alcyonium*. The polyps are united in the proximal parts to form the fleshy mass. The skeleton consists of separate calcareous spicules.

Order 4. *Coenothecalia*. This order is exemplified by the blue coral. The skeleton consists of crystalline fibres of aragonite which are fused into lamellae. The skeleton is massive and perforated with cylindrical cavities where the polyps are lodged. The solenial tubes are long. Example: *Heliopora*.

Order 5. *Gorgonacea*. The corals are compound tree-like in appearance typified by *Gorgonia*. A calcareous or horny skeleton of ectodermal origin is present. Usually dimorphic polyps are borne on the sides of the skeletal axis. The siphonoglyphs are absent.

Order 6. *Pennatulacea*. The colony consists of a long axial polyp with many lateral polyps. The polyps are dimorphic. The lower portion of the axial polyp which forms the stalk is devoid of polyps. The skeleton comprises of calcareous spicules. The "sea-pens" (*Pennatula*) are the commonest examples (Fig. 11.30).

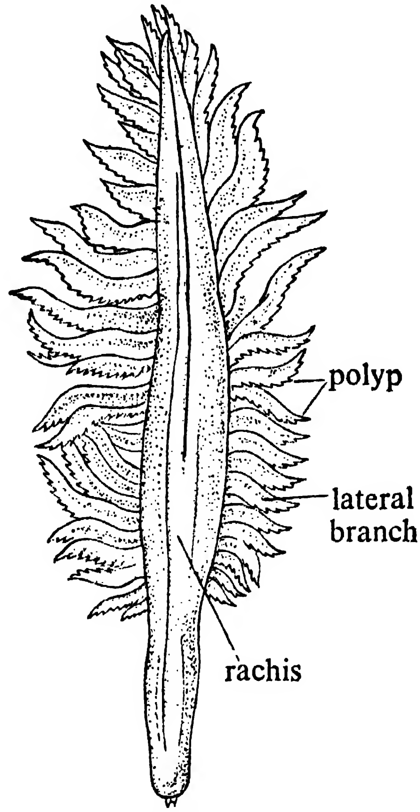


Fig. 11.30. Sea-pen (*Pennatula*)—a typical example of Octocorallia.

GENERAL NOTES ON CNIDARIA

HISTORY. Coelenterates were considered previously as the intermediate forms between plants and animals and were included under *Zoophyta* (Gr. *Zoon*=animal; *phyton*=plant). Trembley (1744) established the animal nature of the hydras and other coelenterates. Depending on the nature of the symmetry of the body, Linnaeus and Cuvier grouped the coelenterates under *Radiata* which included the echinoderms also. Leuckart (1847) first established the differences existing between the coelenterates and the echinoderms and placed the former group in a separate

phylum—the phylum Coelenterata (Gr. *Koilos* =cavity and *enteron* =intestine). However, his group Coelenterata included the sponges and ctenophores. The sponges were later separated as an independent phylum. Many zoologists have included the cnidarians and ctenophores under a common phylum—the phylum Coelenterata. But the recent trend on taxonomy has placed the ctenophores under a separate phylum. Hence Leuckart's Coelenterata is now divided into three phyla—the Porifera, Cnidaria and Ctenophora.

HABIT AND HABITAT. Phylum Cnidaria constitutes the first metazoa proper having well-developed tissue grade of organisation. This phylum is notable in the animal kingdom for exhibiting polymorphism. Most of them are marine and others are fresh-water. They are mostly pelagic animals and are free-living. Instances of commensalism are quite numerous amongst the actinozoans. Parasitism, though very rare, is also not uncommon. *Polypodium*, one of the Anthomedusae, remains as a parasite in the ovary of a fish called Sturgeon. *Cunina*, one of the Narcomedusae, lives parasitically on Trachymedusae. *Peachia*, an actinozoa, leads parasitic life in the larval condition in the radial canals of Scyphomedusae.

POLYMORPHISM IN CNIDARIANS. The cnidarian coelenterates, are notable for polymorphism. In the history of invertebrate evolution, the cnidarians were the first to exhibit the tendency of division of labour through polymorphism. Polymorphism is a phenomenon of existence of different physiological and morphological forms represented by an extensive range of variations within a single species. This phenomenon may be compared to the organ formation in higher forms. To define it in other way, polymorphism means the existence of individuals (Zooids) of a single species in more than one forms and functions. Polymorphism is the most characteristic feature of colonial cnidarians, the individual zooids associated in the colony are rarely similar in forms. The cnidarians which form colonies are characterised by the extreme specialisation of the individuals composing them.

Basic units of Polymorphism. Polyp and medusa are the components and units of polymorphism in cnidarians. Specialisations of these zooids result into polymorphism. Entire polymorphic diversities present in a species of colonial cnidarians can be reduced into two main zooids—the polyp and medusa which remain in organic connection with one another. The structural organisations of the typical polyp and medusa have been fully described previously. These two forms are strictly homologous structures and both of them may be

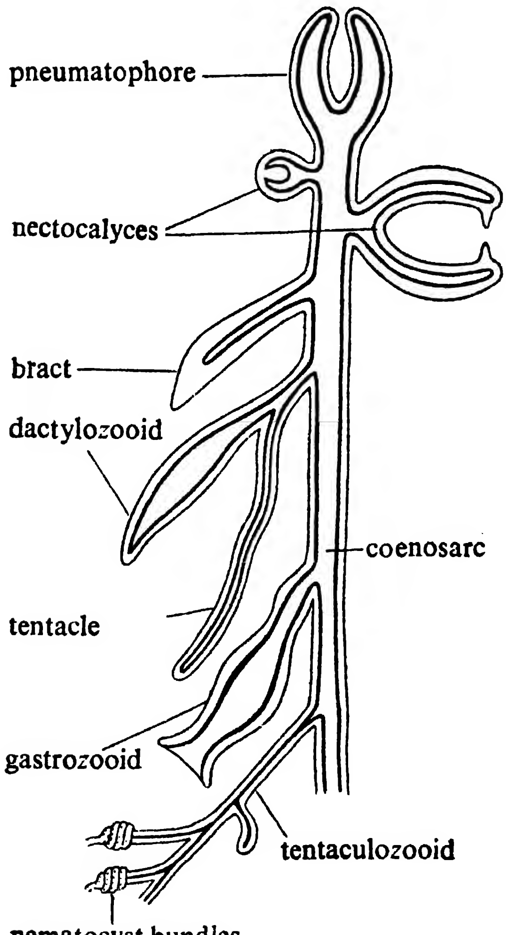


Fig. 11.31. Plan of polymorphic organisation in Siphonophora.

derived from a sac-like body. These two forms alternate with each other in the life-history of a typical cnidarian—the polyp producing medusa asexually and the medusa producing polyp sexually.

Polymorphic variabilities. Polyp and medusa occur in a number of morphological

variations, several of which may be found in a single species. In the class Hydrozoa polypoid and medusoid forms occur; in the class Scyphozoa the medusoid form is predominant while in the class Actinozoa, zooids are exclusively polypoid. Extreme specialisation of forms is exhibited by the members of the order Siphonophora (Fig. 11.31) of the class Hydrozoa. Their colonies exhibit the highest degree of polymorphism. Both polyp and medusa show several modifications, none of which, however, agree fully with typical zooids.

I. Modifications of the Polyp

A. **Gastrozooids of Trophozooids or Nutritive Zooids.** As the name indicates these zooids are meant for feeding (Fig. 11.32A, B). They have cylindrical and funnel-shaped bodies bearing tentacles. Well-formed mouth and coelenteron are present. The gastrozooid exists in the following modified forms:

(1) **Siphon.** The siphon is the only member of the colony which can ingest food. It is a polyp form, but without normal tentacles. A single large hollow tentacle is present. The tentacle is highly contractile and hangs from or near the base (Fig. 11.32A). This tentacle bears lateral contractile branches, called *tentilla.* Each tentilla terminates in a large and complicated knob or coil of nematocysts.

(2) **Siphonozooid.** In *Pennatularia* the gastrozooid is modified to produce a current-producing device at the expense of other structures. They are inhalant in action and are merely warty projections on the body. They are devoid of tentacles, longitudinal muscles but may sometimes possess *septal filaments.* In rare cases, the zooid may possess a single tentacle. The siphonoglyphs are strongly developed. The siphonozooids may remain scattered or may be limited to rachis. Usually they are located on the dorsal side of the rachis in between the leaves. They may be arranged in clusters as in *Renilla.* The siphonozooids may be modified as *mesozooid* and *autozooid.*

(*a*) MESOZOOID. In *Pennatularia,* the

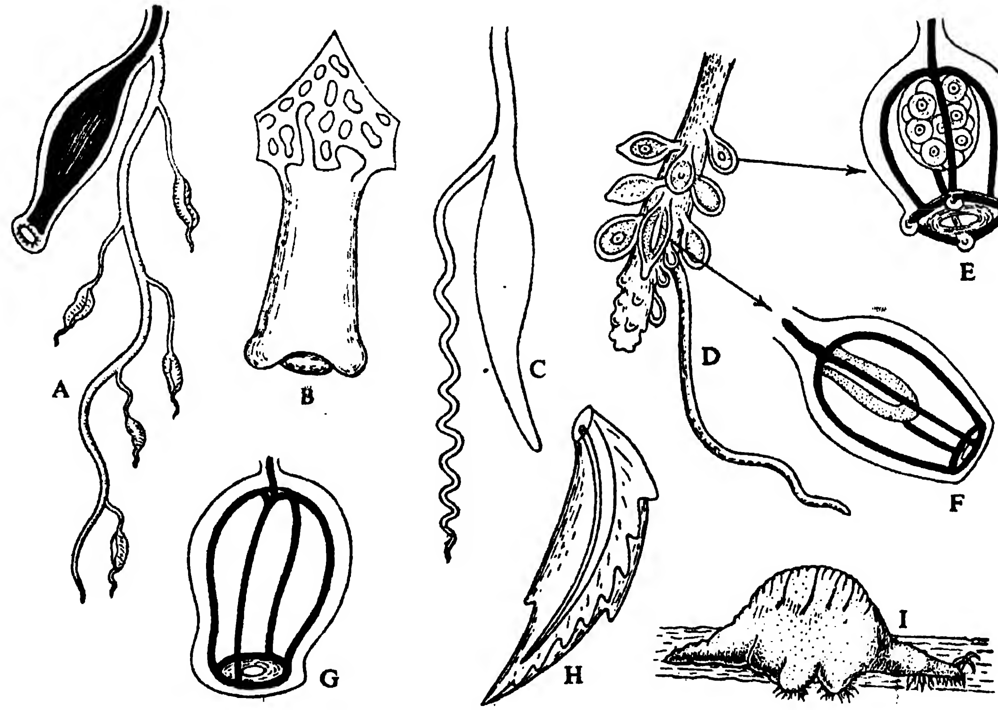


Fig. 11.32. Different types of zooids. (after various sources). A. Gastrozooid with tentacle and bundle of nematocysts. B. Central gastrozooid of *Velella.* C. Dactylozooid with tentacle. D. Gonozooid. E. Female gonophora (medusoid form). F. Male gonophore (medusoid form). G. Nectophore or swimming bell. H. Bract or hydrophyllium. I. Float of *Physalia.*

siphonozooids are further modified to act as exhalant zooids. They are also known as the '*Mesozooids of Hickson*'. They possess well-formed septa and retractor muscles. Siphonoglyphs are very weak.

(*b*) Autozooids of anthocodia. These are also present in *Pennatularia.* They may be retractile and function as the feeding zooids of the colony. They may be differentiated into a calyx and are always absent from the dorsal and ventral surfaces of the rachis. The siphonoglyphs are reduced or absent.

(3) **Gastrozooids of Millepora.** On the surface, there are *gastropores* through which protrude polyps having four to six tentacles reduced into nematocyst knobs. The body of the polyp is very short (See Fig. 11.29C).

B. **Dactylozooids or Tasters or Feelers or Macrozooids.** These protective zooids are actually derived from the gastrozooids by the reduction or total loss of mouth. They are elongated and highly extensible. The tentacle is usually capitate (Fig. 11.32C). The dactylozooids exhibit following structural variations :

(1) **Tentaculozooids.** In *Hydroctena*, the dactylozooid assumes a long tentacle-like appearance. They may be definitely arranged in relation to the gastrozooids and are usually situated at the margin.

(2) **Spiral zooids.** In *Hydroctena* the spiral zooids with capitate tentacles remain scattered throughout the colony.

(3) **Sarcostyles or Nematophores.** In Plumulariidae, the sarcostyles spring from tiny thecae (nematothecae) located on the stems and on the hydrothecae (usually three to each) of the gastrozooids. The nematophores are usually with club or capitate ends, beset with nematocysts or adhesive cells or both.

(4) **Palpons.** The palpons in Siphonophora consist of simple hollow tentacle-like bodies which spring from the margin of the body. The palpons act as the dactylozooids in *Velella* and *Porpita.* In these two forms, the palpons may remain associated with the gonophores and are called as gonopalpons.

(5) **Cyston.** In Siphonophora, a distal pore present in the dactylozooid is called the cyston. It is excretory in function.

(6) **Dactylozooid of Millepora.** On the surface of the body there are dactylopores from which project long, filamentous, mouthless dactylozooids with irregularly disposed tentacles (Fig. 11.29C).

C. **Gonozooids or Blastostyles.** These zooids are the reproductive individuals of the colony. They are modified polyps that produce medusoid forms or their morphological equivalents by budding. They are club-shaped bodies devoid of mouth and tentacles. The coelenteron is greatly reduced (Fig. 11.32D). The typical form becomes modified in different members.

(1) **Gonosiphon.** In *Velella* and *Porpita* the gonozooids may resemble gastrozooids and may even possess a mouth. The tentacles are absent.

(2) **Gonodendron.** In Siphonophora, gonodendrons are present as branched stalks which bear grape-like clusters of gonophores and are usually provided with a long retractile *gonopalpon.*

(3) **Gonopalpon.** In Siphonophora, a tentacle-like dactylozooid remains associated with the gonophores and is then termed as gonopalpon.

D. **Special types of Zooids**

(1) **Gonostyles or Secondary Siphonozooids.** In *Porpita*, the gonostyles are primarily reproductive in function and may secondarily be nutritive. The mouth and coelenteron are present. The gonads remain attached with the siphonozooids.

Some authors claim Hydrorhiza and Hydrocaulus of Obelia to be special types of Zooids.

(2) **Hydrorhiza.** In *Obelia*, the hydrorhiza acts as the organ of attachment for the whole colony.

(3) **Hydrocaulus.** In *Obelia*, the hydrocaulus, arising from the hydrorhiza, bears different zooids and helps to convey the food matters to the different parts of the colony.

II. **Modifications of medusoid form**

A **Nectocalyx or Nectophore or Swimming-bell.** This form is present in Siphonophora excepting *Physalia.* It has a typical medusoid form having a bell, velum, four radial canals and a ring canal, but is devoid of mouth, manubrium, tentacles and sense organs (Fig. 11.32G). The body is bilaterally flattened, may be prismatic or may be elongated. In bilateral forms, two

of the four radial canals, take sinuous courses. The body is highly muscular and helps in the process of locomotion.

B. **Bract or Hydrophyllium or Phyllozooid.** These forms do not resemble the medusa, though they are actually medusoid in origin. They have thick gelatinous, prismatic or leaf-life or helmet-shaped bodies having simple or branched coelenteron. These forms are present in Siphonophora (Fig. 11.32H).

C. **Pneumatophore or Float.** This type is present in siphonophores excepting *Diphyes*. It is hydrostatic in function and is represented by an inverted medusoid bell devoid of mouth and tentacles (Fig.11.32I). The mesoglea is absent. It consists simply of an external exumbrellar wall called the *pneumatocodon* and an internal subumbrellar wall known as the *pneumatosaccus* or *air sac*. The original opening of the air sac is directed upward. This opening may be closed or reduced to a pore guarded by a sphincter muscle. The air sac is usually lined by a chitinous layer secreted by the ectoderm. At the bottom of the air sac there is usually an expanded chamber termed as *trichter* or *funnel*. The ectodermal lining of the trichter is modified into *gas gland*. The air sac is filled up with oxygen, nitrogen, argon, etc. Normally one pneumatophore is present in a colony.

D. **Aurophores.** These forms help in swimming and excretion. It is ovoidal in shape. A part of the pneumatophore becomes partially constricted off to form a bell-like aurophore which remains amongst the nectophores. The aurophore remains in communication with the pneumatophore as well as with the exterior.

E. **Gonophores.** These types of zooids are reproductive in function. Gonophores may occur singly or they may be present in clusters. They look like medusae in having bell, velum, radial canals and manubrium (Fig. 11.32E, F). Gonads are situated on the manubrium. Mouth, tentacles and sense-organs are lacking. Gonophores are dioecious, but the colony is hermaphrodite. The female gonophores are medusa-like, but the male gonophores are sac-like. From these medusa-like gonophores, gradations of reduction from umbrella-like to sac-like forms are encountered. In most of the members of Hydroidea, the gonophores are sessile. The following stages in the process of reduction are recognised :

(1) EUMEDUSOID STAGE. This is observed in *Tubularia*. In this form, tentacles and other marginal structures are lacking.

(2) CRYPTOMEDUSOID STAGE. This stage is seen in *Clava*. The body lacks velum and radial canals.

(3) HETEROMEDUSOID STAGE. This stage is noticed in the family Plumulariidae where the endoderm is inactive.

(4) STYLOID STAGE. This stage is seen in *Eudendrium*. They are just the original ectodermal and endodermal protruberances.

The cryptomedusoid, heteromedusoid and styloid stage of the gonophores are usually designated as sporosacs.

Origin of Polymorphism. Polymorphism in cnidarians is virtually regarded to be the division of labour, where different zooids perform diverse functions. As regards the origin of polymorphism in cnidarians, the following theories have been advanced :

I. **Poly-organ theory.** The main supporters of the theory are Huxley, Metschnikoff and Eschscholtz. They regard that each polymorphic colony is an individual and the polyps or medusae, which are budded off from it, are the organs.

II. **Poly-person theory.** The supporters of this theory are Vogt, Leuckart, Gagenbaur, Chun and Kukenthal. This theory suggests that cnidarian colony is constituted of independent and separate individuals which remain in organic connection with one another. According to this view each zooid is a separate individual, where some portions may be either lost or obliterated in course of time.

III. **Medusa theory.** This theory is forwarded by Haeckel, Balfour and Sedgwick. The theory advocates that the primitive zooid of polymorphic colony was, with all probabilities, a medusa which produced other medusae by the process of budding. These medusae possess the power of locomotion as well as the power of reproduction. In this view many organs of the colony are nothing more than the parts of such medusoid individuals which have subsequently shifted their attachments from the original medusa.

This concept makes a compromise between the two previously described theories. It agrees with the second theory in asserting the colonial nature and also admits that asexual reproduction and specialisation of certain parts of the colony, as advocated in the first theory.

Relationship between Metagenesis and Polymorphism. The advent of polymorphism in cnidarians resulted into division of reproductive processes—the polyp is only capable of asexual reproduction, while the sexual reproduction is only confined to the medusae or the gonophores (modified medusae). The fertilized egg from these gonophores never develops into the medusa or the gonophore that produces it, but always transforms into a polyp form and thus rendering the life-history complicated and leads into metagenesis.

The relationship between metagenesis and polymorphism has raised the question—is metagenesis an outcome of polymorphism or has it led to the emergence of polymorphism? A discussion on the existence of different grades of metagenesis in cnidarians will help us to find a logical answer.

Gradations of Metagenesis. Four different forms of life-histories are seen in the cnidarians which exhibit a trend towards complexity. These different grades are :

Monomorphic form. Typical representative is *Hydra*. Fresh-water forms lack free larval stage but the marine forms do possess it.

$$\text{Polyp} \rightarrow \text{Egg} \rightarrow \text{Polyp}$$

Dimorphic form. Typical representative is *Aurelia.*

$$\begin{tikzcd}
\text{Polyp} \arrow[d] \arrow[dr] & & & \text{Polyp} \arrow[lll] \\
\text{Medusa} \arrow[d] & \text{Medusa} \arrow[d] & & \\
\text{Sperm} \arrow[r, phantom, "+"] & \text{Egg} \arrow[rr] & & \text{Planula larva}
\end{tikzcd}$$

Trimorphic form. Typical representative is *Obelia.*

$$\begin{tikzcd}
\text{Gastrozooid} \arrow[r, dash] & \text{Polyp} \arrow[r, dash] & \text{Blastostyle} \arrow[d] \arrow[dr] & \\
& & \text{Medusa} \arrow[d] & \text{Medusa} \arrow[d] \\
& \text{Planula larva} & \text{Egg} \arrow[l] \arrow[r, phantom, "+"] & \text{Sperm}
\end{tikzcd}$$

Polymorphic form. The classical example is the Siphonophora.

$$\begin{tikzcd}
\text{Gastrozooid—Dactylozooid} \arrow[r, dash] & \text{Polyp} \arrow[r, dash] & \text{Gonozooid} \arrow[d] \arrow[dr] & & \\
& & \text{Medusa} \arrow[d] & \text{Medusa} \arrow[d] \arrow[r, dash] & \begin{array}{l}\text{Pneumatophore}\\ \text{Nectocalyx}\\ \text{Bract}\\ \text{Aurophore}\end{array} \\
& \text{Planula larva} & \text{Egg} \arrow[l] \arrow[r, phantom, "+"] & \text{Sperm} &
\end{tikzcd}$$

Examination of these grades has given rise to two plausible answers. One view holds that ancestral cnidarians were polyps and the medusae developed secondarily from it. The polyp passed the function of sexual reproduction to the medusa which established the cycle of metagenesis. The alternate answer is that the original cnidarians were medusae and that polyp is a larval stage. The life-history of the Trachymedusae, a primitive group of cnidarian, lends support to this contention. In this group the life-history is represented as :

$$\begin{tikzcd}
\text{Medusa} \arrow[rr] & & \text{Egg} \arrow[d] \\
\text{Actinula} \arrow[u] & & \text{Planula} \arrow[ll]
\end{tikzcd}$$

Here actinula stage fixes itself like a polyp and asexually produces medusoid form. This evidence together with the nature of development of a siphonophore colony, also strongly endorses the second view.

HISTOLOGICAL ORGANISATION. All cnidarians are diploblastic tissue-grade animals, i.e. the body is composed of two distinct cellular layers. The ectoderm lies on the outer side and the inner layer is called the endoderm. In between them there is mesoglea which fails to form a distinct cell layer.

Ectoderm. In most cases it is distinctly cellular. Presence of ciliated ectoderm in larval cnidarians is usually seen. The cellular ectoderm is mainly composed of the supporting cells, called the **Epitheliomuscular cells.** They are usually cuboidal or

columnar in shape. They may be thin and flattened (exumbrellar surface of medusae) or may be slender and elongated (in anemones). The base of the cell-types possesses contractile extensions. These contractile extensions are absent in some trachylines, in majority of scyphozoa and actinozoa where the basal end is simply amoeboid. It is observed that distinct fibrils are present in epitheliomuscular cells of Hydra which render stiffness and elasticity to the body.

The ectoderm of the tentacles and the anterior region of the body of all cnidarians contain numerous characteristic **Nematocysts.** They are very specialised structures having their origin from the interstitial cells. The nematocysts are the most remarkable cellular derivatives and are the diagnostic feature of cnidarians. The detailed structural organisation of a typical nematocyst has already been described in biology of Hydra. Two primary types of nematocysts are encountered in cnidarians.

(1) *Spirocysts*. This type is present in Zoantharia. The capsule is very thin and single-walled. The capsular wall is permeable to water. The thread tube is of even diameter. It is very long, unarmed and remains spirally coiled.

(2) *Nematocyst proper*. This type of nematocyst is the characteristic of other cnidarians. The capsule is very thick and is double-walled. The capsular wall is not usually permeable to water. The thread tube may be of variable length and is usually armed. The swollen basal part of the thread tube which is devoid of spines is called the *butt*. This type is usually divided into several types, depending upon the nature of the thread tube.

I. The tube is closed at the terminal end. This includes two types.

(*i*) *Rhopaloneme*. It is present in *Diphyes*. The tube forms an elongated sac-like structure.

(*ii*) *Desmoneme* or *volvent*. It is present in Hydra. The thread tube is coiled like the cork-screw.

II. The tube is open at the terminal end and is devoid of butt. This type has certain varieties.

A. *Isorhiza or Glutinant*. When the tube is of uniform diameter and found in Hydras, corals, anemones and medusae.

(*i*) *Holotrichous*. When spines are present throughout.

(*ii*) *Atrichous*. When the spines are totally absent.

(*iii*) *Basitrichous*. When the spines are restricted at the base.

B. *Anisorhiza*. When the type is expanded at the base with spines throughout the length. Example is *Tubularia*.

(*i*) *Homotrichous*. Spines are of same sizes.

(*ii*) *Heterotrichous*. Spines are of unequal sizes.

III. The tube is open at the terminal end and possesses a definite butt.

A. The butt is of same diameter throughout its length.

(*i*) *Microbasic mastigophores*. The tube is continued beyond the butt, but never exceeds more than three times the length of the capsule. This type is present in anemones.

(*ii*) *Microbasic amastigophores*. The tube is short and never extends beyond the butt. This type is present in *Sagartia*, an anemone.

(*iii*) *Macrobasic mastigophores*. The butt is more than four times the length of capsule. This type is present in Millepora.

(*iv*) *Macrobasic amastigophores*. The butt is very long and the tube does not extend beyond the butt as seen in many anemones.

B. The butt is dilated at the base.

This type includes the *stenosteles* or *penetrant* types which are present in Hydra.

C. The butt is dilated at the tip. This type of nematocysts is called as the *eurytele*.

(*i*) *Homotrichous microbasic*. The butt is small and the spines are of same size. This type is present in *Pteroclava*.

(*ii*) *Heterotrichous microbasic*. The butt is small and the spines are of unequal size. This type occurs in *Eudendrium*.

(*iii*) *Telotrichous macrobasic*. The butt is longer with spines at the distal end. This type is also present in *Pteroclava*.

(*iv*) *Merotrichous macrobasic*. The butt is also longer with spines not at the tip as observed in some tubularian hydroids.

The nematocysts develop inside the interstitial cells. The interstitial cells

containing the nematocysts are called **Cnidoblasts.** Different types of nematocysts perform different functions. The nematocysts have specialised regional distribution in the body column of the organism. Although they are present in abundance in the tentacular and oral regions of the body, they actually originate elsewhere. The actual mode of migration is already discussed in the description of Hydra. The size of nematocysts varies greatly amongst the different groups. The largest nematocyst is found in *Halistemma* where the length of the capsule may reach 1–12 mm. As regards the actual mechanism of discharge of nematocyst thread, nothing definitely can be said. Any stimulus, whether chemical or mechanical, may cause violent expulsion of the nematocyst. Increased osmotic pressure in the capsule helps in discharging the thread tube out. The chemical nature of the substance ejected out from the nematocysts is also not properly known. It is highly toxic and causes paralytic effects on the prey after injection. Biochemical analysis of the extracts from the nematocysts of different coelenterates showed that the anaesthising toxins, such as the *hypnotoxin*, *thalassin*, *congestin* etc., are present which are protein in nature.

Gland cells are also quite abundant in the ectoderm. The basal disc region of Hydra is composed entirely of tall basal cells which contain muscular extensions. In the sea-anemones the entire body contains gland cells amongst the epitheliomuscular cells. They help in adhesion of the organism.

Sensory cells in the form of slender, elongated bodies with one or two or more sensory motile bristles are quite abundant. Ectodermal nerve cells in the form of bipolar or multipolar ganglionic cells are present in the ectodermal and mesogleal layers.

· Another most vital ectodermal cell-type which plays the most significant role in the organisation of Cnidarians, is the **Interstitial cell** or **Subepithelial cell.** Like the *amoebocytes* or *archaeocytes* of sponges, the interstitial cells in cnidarians are perennial undifferentiated embryonic cells. They help in the production of nematocysts, formation of gametes and in the process of budding and regeneration.

Mesoglea. The consistency of this particular layer in cnidarians varies greatly. In most hydrozoans, cellular elements are absent in it in the polyp stage but in the medusae some fibres of unknown origin are present. The scyphozoan medusae contain few scattered amoeboid cells and fibres in this intermediate layer. But in actinozoans the mesoglea is highly developed with considerable thickness and contains distinct amoeboid cells and connective tissue fibres. Recent studies have shown that mesoglea of Hydra is composed of secretory collagenous element (connective tissue).

Endoderm. The endoderm is largely composed of **Nutritivemuscular cells.** In some polypoid cnidarians, the nutritive-muscular cells contain contractile extensions which run as circular muscles. But such contractile extensions are lacking in medusae. The endoderm contains **gland cells** which secrete gastric juices. The nerve cells and sensory cells are present but in lesser number. Presence of symbiotic forms as *Zoochlorellae* in green Hydra and *Zooxanthellae* in some corals and anemones is also seen.

SKELETON IN CNIDARIANS. The coral islands and the coral reefs are the secretory products of some skeleton forming cnidarians, especially the stony corals belonging to the order *Madreporaria.* The corals exhibit extensive diversities in structure and form. They are composed of hard sleketon of calcium carbonate. Starting with a very simple pattern, myraids of tiny creatures built up huge coral reefs or islands of various shapes and sizes. The calcareous skeleton is secreted by the calicoblastic layer (modified ectoderm) at the basal region of the polyp. The coral forming creatures resemble closely a hexamerous anemone, the pedal disc of which is occupied by the skeletal cup.

Structure of coral. Coral is secreted by some coral-orming actinozoa. The skeleton of a solitary polyp is known as the *corallite* (Fig. 11.33) and many corallites combine to form the skeletal mass. The skeleton as a whole is known as the *corallum.* The structure of a corallum will be clear from the detailed structural organisation of a single corallite.

Structure of a corallite. Each corallite consists of a cup containing vertical ridges radiating from the centre to the periphery. The bottom of the cup beneath the polyp is designated as the *basal plate.*

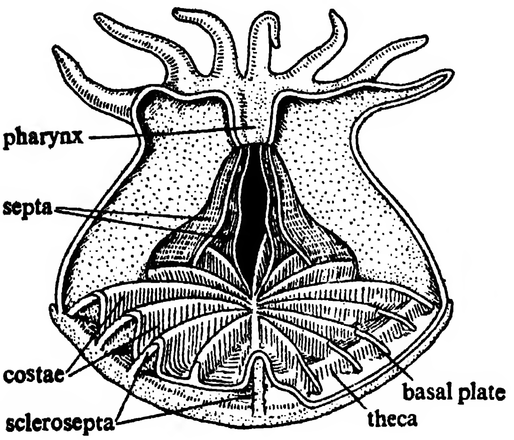


Fig. 11.33. Structure of a corallite, *Astroides.* (After Kaestner).

The wall of the cup enclosing the aboral portion of the polyp is termed as the *theca.* The ridges of the cup are called the *skeletal septa* or *sclerosepta.* The formation of theca may be an independent process or may arise by the fusion of the outer ends of the sclerosepta and the theca thus formed are called the *pseudotheca.* The inner ends of the sclerosepta are fused to a central columnar skeletal mass, termed as the *columella* which may arise independently as the outgrowth of the basal plate or may be formed by the union of the central ends of the sclerosepta. The columella formed by the last process is termed as the *pseudocolumella.* A secondary wall or *epitheca* may be formed outside the theca. The epitheca is separated from the theca by a space and this space is crossed by continuations of the sclerosepta called the *costae.* Small ridges called the *pali* are present between the columella and the main parts of the sclerosepta. There are horizontal plates between sclerosepta, which, when incomplete, are called *dissepiments* and when complete, are known as *tabulae.* The sclerosepta are usually spiny. The sclerosepta present in a corallite are definitely related to septa and typically occur in hexamerous cycles: 6 primaries, 6 secondaries, 12 tertiaries, 24 quarternaries, etc. The sclerosepta are commonly endocoelic in origin.

Types of coral. The classification of coral is unsatisfactory. Corals are divided into several types depending upon the habit or association and upon the structure.

I. **Solitary corals.** The typical examples of the solitary corals are the *Fungia,* (Fig. 11.34A), *Flabellum, Caryophyllia, Balanophyllia,* etc. They are solitary corals having disc or cup or mushroom-shaped corallites and measuring about 5 mm to 25 mm across. The corallites are often without a theca and lie loose on the bottom and remain attached by a stalk. They may reproduce by longitudinal fission or by budding from any part of the body surface. The sclerosepta of the buds are formed from those of the parent.

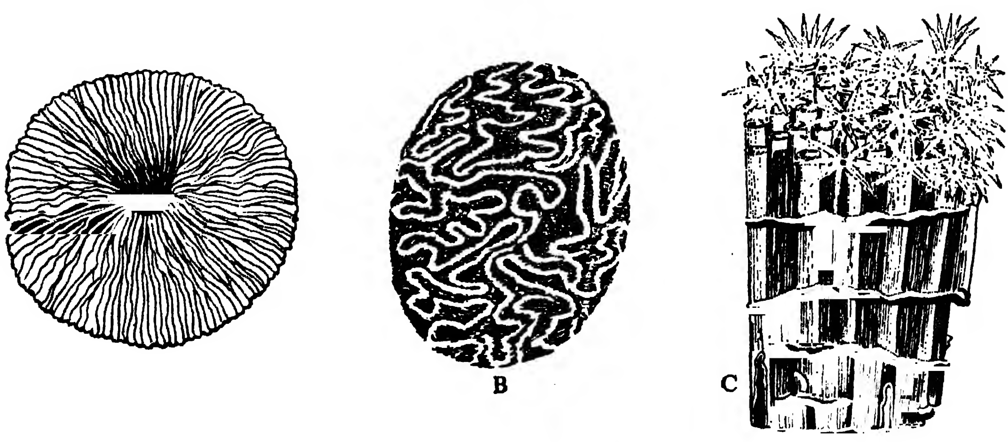


Fig. 11.34. Different types of Anthozoan corals. (After Kaestner). A. *Fungia* (Mushroom coral). B. *Meandrina* (Brain coral). C. *Tubipora* (Organ pipe coral).

II. **Colonial corals.** The typical examples of the colonial corals are *Oculina, Favia, Madrepora, Meandrina, Tubipora,* (Fig. 11.34B, C), etc. Most of these corals are colonial and usually form low flat plates or spherical masses or cups or vases. They may be branched also. The branched forms have short stout or long slender branches. The colonies are formed by asexual methods from a single sexually produced polyp. The colony is largely composed of calcareous secretion and the surface is only occupied by living individuals. The polyps constituting the colony may be widely separated from each other with separate theca or the thecae of the different polyps may fuse together to form a common wall. The polyps are usually small, varying from 1 mm to 3 cm in length. The space between the thecae of coral colonies is occupied in living state by coenenchyme.

On the basis of its structural organisation, the corals can be divided into three types :

1. **Imperforate or Aporose.** These corals have compact thecae and sclerosepta. The loculi are usually separated off by dissepiments or synapticulae. The examples are: *Flabellidae, Turbinolidae, Oculinidae, Caryophyllidae, Faviidae.*

2. **Perforate.** The corallum is extremely porous and is of loose construction. The examples are: *Eupsammidae, Acroporidae, Poritidae, Madrepora.*

3. **Fungid.** They may be either perforate or imperforate and have laminated septa joined by synapticulae. The corals belonging to the family *Fungiidae* are included under this category.

Formation of Coral. The actual method of secretion of coral and the subsequent stage of formation are not very clearly understood. But the following account will give an idea about its formation. Secretion of coral does not commence until twelve primary mesenteries are attained by the polyp. Secretion of calcareous materials which either immediately crystallise or crystallise by the interaction with chemical substances present in sea water, transforms into a calcareous mass. The calicoblast layer forms minute nodules at the base of polyp. The nodules unite to form *prototheca* which becomes gradually thickened and later assumes a cup-shaped structure. At this stage the body-wall of the living polyp may or may not overflow the edge of prototheca. In the former case, the growth of the prototheca is brought about by the calicoblasts. The cup is now called the *theca* and the overflowed tissue is called the *episarc*. The episarc of the primary zooid thus overflowed on the substratum, gives rise to the successive layers of skeleton, called the "Coenenchyma". By the process of asexual reproduction new zooids are developed near the primary one. The episarc, independent theca and septa are gradually formed in secondary zooids also. The skeleton of different zooids remains interconnected with the primary one. Many corallites constituting the corallum are formed. Separate film of skeletal material is formed outside the theca and this layer is called the *epitheca*. Six to twelve ectodermal infoldings are formed at the base of the polyp. Secretion of skeletal material in those grooves takes place and sclerosepta are formed within the theca. Gradually the secondary and tertiary sclerosepta are developed in spaces between mesenteries and they alternate with the mesenteries. The edges of the theca become extended and the polyps disappear from the cup. The vertical space thus formed is filled with secretion which may be in the form of these plates. In many cases polyps may be connected by canals. The soft parts are washed away and the calcareous masses are left on the spot.

Coral reefs. Corals in course of time form coral reefs and coral islands. Although the stony corals constitute the main bulk of the coral reefs, other organisms also contribute to the formation. To name a few, they are the coralline algae, foraminifera, some calcified alcyonarians, some alcyonaceans. In addition to these organisms, sponges, anemones, starfishes, sea urchins, crabs, some snails and bivalves also take part in the process.

Formation of coral reefs needs particular environmental conditions. The reef-building corals require certain requisites for the formation of coral reefs. They require warm and shallow water. Reef-building corals cannot stand the temperature below 18°C and they show flourishing growth above 22°C. The reef building corals are restricted in their vertical distribution and they do not form reef below

fifty metres from the sea level. Another physical factor, light, is also very much essential. It has been shown experimentally that they fail to grow in shady places and may die if kept in total darkness. Below the depth of fifty metres corals are present but they do not form reefs, because deep-sea forms are mainly the solitary corals.

Coral reefs are usually divided into three primary types, the *Fringing reefs*, *Barrier reefs* and *Atolls*. Each type of the coral reefs has got some characteristic features.

Fringing Reef. The fringing reef (Fig. 11.35A) is extended from the shore up to 400 metres and takes the contour of the shore. It has a reef edge, called the *front* where the most active coral growth occurs. Between the front and the shore there lies a more or less flat surface which is known as the *reef flat*. The fringing reef is largely composed of coral, sand, mud, dead coral and other debris. It is partly composed of coral colonies and other animals. Fringing reef is cut by a narrow water channel (lagoon) and the depth of the water channel is 37 to 55 metres.

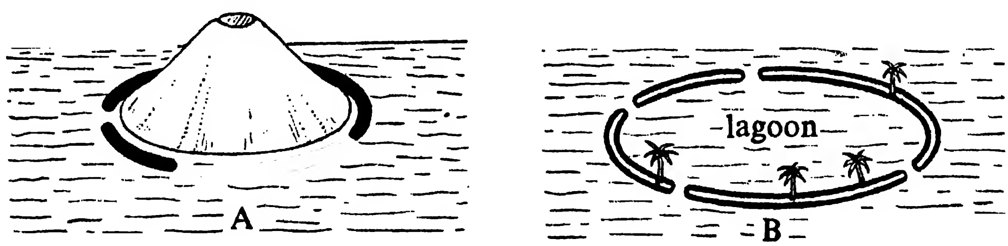


Fig. 11.35. A. Fringing reef. B. Atoll.

Barrier Reef. The typical example of the barrier reef is the Great Barrier Reef of the northern coast of Australia. It resembles the fringing coral reef, but it follows the contour of the shore less regularly. The reef flat is separated from the shore by a lagoon of 90 to 110 metres deep.

Atoll. The atoll (Fig. 11.35B) is more or less circular or horse-shoe-shaped reef and encloses a lagoon which varies from a few kilometres to 64–80 kilometres across. The depth of the lagoon is 37 to 55 metres. The lagoon usually contains inner islands and reef.

Views regarding coral reef formation. The reef-building corals obey certain conditions to form coral reefs. They do not grow well below 45 metres, they require optimum temperature and light. Many theories have been put forward to explain the formation of coral reefs. Some such theories are discussed below :

Darwin-Dana Subsidence theory. This theory has its origin from the observations of Darwin during his remarkable voyage in the ship, *H.M.S. Beagle* as a naturalist between 1831 and 1836. The theory states that from fringing reefs arise other types of coral reefs. Fringing reefs are formed on shores which are inclined downward. Sometimes the shore between the developing fringing reef and the land mass sinks. The fringing reef thus turns into a *barrier reef*. The barrier reef and the main land mass always have sea water between them. In case the main land mass is an island and it itself subsides completely under water, the reef turns into an atoll.

Semper-Murray Solution theory. After exploring the conditions of life in the sea, Sir John Murray advanced the view that corals grow on the highest peaks of the ocean bottom. The deposition of sediments brings them to an optimum level. The barrier reefs and atolls are produced by the better growth of the corals in the edges of the coral deposition and by the solution of its inner part.

Submerged Bank theory. This concept is supported by many investigators of the present time. According to this theory the coral reefs are formed on flat surfaces which at first remain in lesser depths. Such surfaces with growing reefs later on submerge slowly and go down to greater depths. This theory denies the transition of one common type of reef into different types. It advocates an independent origin of different types of reefs. Further,

regarding the shape of the atoll, it lays importance on the winds and water currents.

Daly Glacial-control theory. This theory advocates that during the last glacial period, formation of ice caps lowered the level of water of the ocean. At that time extreme cold temperature prevailed. Subsequently the ice melted and the temperature rose. The corals began to grow upon the flat platform of the ocean bottom and kept pace with the rising level of the ocean. The support to the Daly Glacial-control theory was given by calculating that almost all the existing coral reefs had been formed since the Ice-age.

As regards the formation of atolls, Huxley and Wells have put forward the view

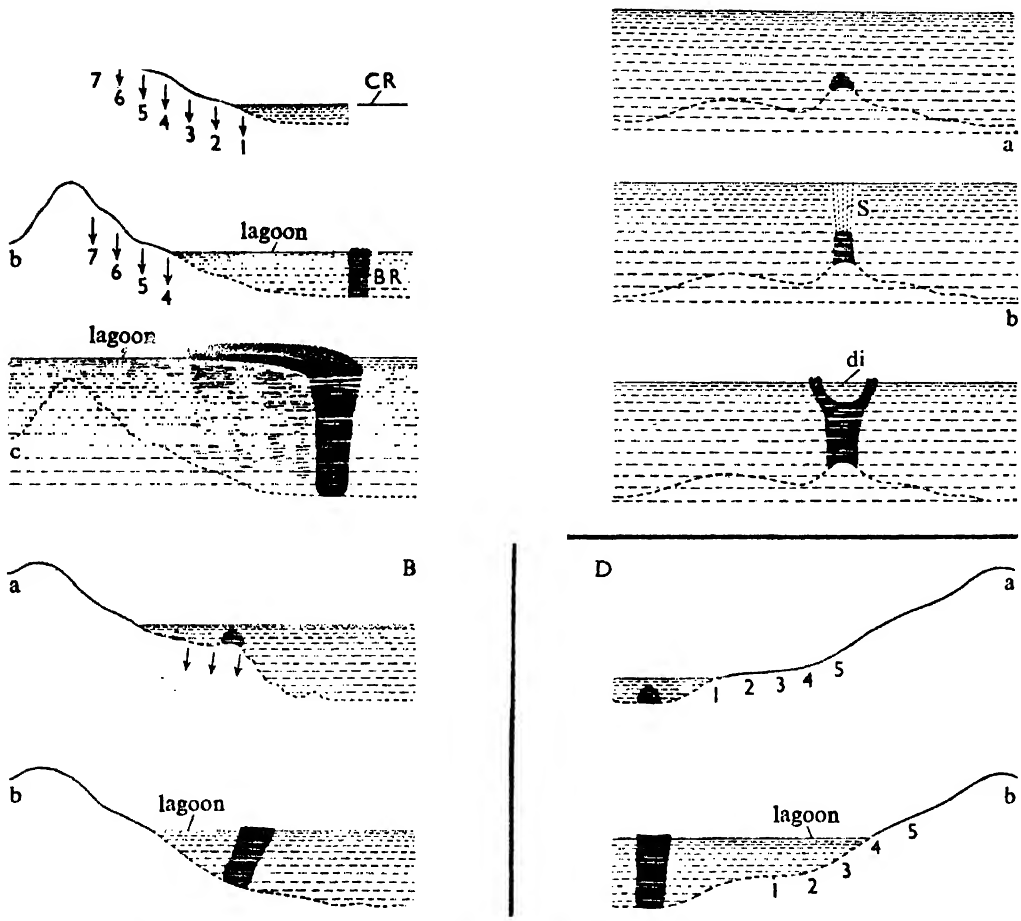


Fig. 11.36. Diagrammatic representation (sectional view) explaining various theories regarding coral reef formation.

A. *Darwin-Dana Subsidence theory*—a. Beginning of reef formation (CR) at shallow depth. b. Inclined part of the shore subsides (indicated by numbers) and the corals grow to form barrier reef (BR). c. Showing the extreme result of such subsidence. When coral reef grows in a horse-shoe or circular shape around the completely subsided land mass, an atoll is formed.

B. *Submerged Bank theory*—a. Beginning of a coral reef in the ocean bottom. b. The ocean bottom submerges gradually and the reef grows upwards.

C. *Semper-Murray Solution theory*—a. Initiation of coral reef on the elevated part of ocean bottom. b. Deposition of sediments(S), i.e. salts, clay, etc., on the reef. c. The reef reaches the surface and its central part dissolves (di) to form lagoon and the margin thickens.

D. *Daly Glacial-control theory*—a. Glaciation reduced the height of the ocean by withdrawing water to form ice caps (No. 5 indicates former height and No. 1 is the height after withdrawal). Coral reefs started to form at that time in the shallow depth. b. As the ice melted, the level of water rose along with the growth of the coral reef.

that atolls might have come into existence in other ways. From the geological point of view, submarine eruptions are quite frequent in the ocean bottom. By such catastrophe, volcanic cones were raised above the sea level and the erosive action of the sea waves became so severe that their tops were eventually smoothed off to provide an ideal platform for the future atoll.

Despite great controversies regarding the origin of coral reefs, the most obvious conclusion that may be drawn is that the coral reefs of the present day grew on submerged land. This contention is attested by evidences from different angles. The rate of coral growth is of much importance for the explanation of the theories on this line. But the observations showed that the growth of coral is extremely variable.

In spite of all controversies it cannot be denied that the coral and the coral reefs played great and significant role in geological history. They protect the coast from the erosive actions of the sea waves.

PHYLOGENETIC RELATIONSHIPS OF THE CNIDARIANS. The following account will give an outline idea about the interrelationships between the different classes of the phylum Cnidaria. Class Hydrozoa represents the most primitive forms amongst the Cnidarians. The lowest hydrozoan form is exhibited by Hydra and the hydrula stage of some Hydrozoa. The relationship between Hydrozoa and Scyphozoa is not very clear. In spite of this, it can be suggested that they have been derived from a common trachyline stem. Some of the scyphozoan characteristics, such as the marginal notches, gastric pouches, tentaculocysts, etc., have already been evolved in the Narcomedusae of class Hydrozoa. *Nausithoe*, belonging to the order Coronatae possesses a branched larval form which resembles a hydroid colony very closely. After their origin from the common stem, the hydrozoans and the scyphozoans have diverged greatly and the changes undergone by the scyphozoan 'polyp' (*Scyphistoma*) are the formation of mesenteries, gastric tentacles, etc., which are primarily for increasing the digestive surfaces in the coelenteron. Amongst the scyphozoans, the *Stauromedusae*, for its polypoid characteristics and lack of tentaculocysts, are long being regarded as the ancestors of the other scyphozoans form. But this seems to be improbable if we consider the coelenterate stem to be a medusa. It is attested by many that the Stauromedusae represent a post-larval stage. They are not in the direct line of Scyphozoan evolution but lie very close to that line. *Cubomedusae* are the most primitive forms existing amongst the scyphozoans. To correlate them with higher order leads into difficulties, because its developmental dynamics are not fully known. The *Coronatae*, with all possibilities, are very near to the direct line of the scyphozoan ascent.

The Actinozoans lack medusoid stage and the polypoid stage reaches its climax. The similarities of the *Scyphistoma* larva and the actinozoan polyp establish a common origin of the Scyphozoa and the Actinozoa. The similarities are :

1. Gastric tentacles of Scyphistoma correspond to the mesenteric filaments of Actinozoa.
2. Gonads are endodermal in origin.
3. Septa have retractor muscles.

But difficulties in such assumption lie in the absence of stomodaeum in Scyphistoma and the symmetry of body forms (tetramerous symmetry in Scyphistoma and the octomerous bilateral symmetry in Actinozoa). It can best be suggested that the Scyphistoma and the ancestral form of Actinozoa have undergone parallel evolution after their origin from a remote common ancestor. Of the actinozoans, three distinct evolutionary lines are recognisable :

1. *The antipatharian-cerianthid line.* It constitutes the most primitive living groups of Actinozoa. They possess simpler orientation of septa and tentacles and have ill-developed mesoglea.

2. *The alcyonarians or octocoralline line.* According to Hyman, octocorallines and hexacorallines probably had a common ancestry. The ancestor was a small polyp with eight tentacles and poor musculature.

3. *The zooanthid-anemone or hexacorralline line.* The presence of *Edwardsia* stage in all the members of this group indicates that a form like this was probably the ancestor. It was devoid of basilar, sphincter and retractor muscles, but had "complete ectodermal muscle layer" as quoted by Hyman.

The tendencies to form colony and skeleton have evolved independently amongst different members of Actinozoa and as such they have little phylogenetic significance.

WHY ARE THE CNIDARIANS GIVEN A PHYLETIC STATUS?

Many Zoologists still combine the cnidarians and the ctenophores under a common phylum—the Phylum Coelenterata. Both the cnidarians and ctenophores have many common characteristics, of which the coelenteron or enteric cavity is noteworthy. Both of them stand at a low level of metazoan organisation with a distinct radial symmetry. This symmetry becomes markedly biradial in some cases. But the recent workers on this line advocate the splitting of the original phylum Coelenterata into two distinct and separate phyla—*Phylum Cnidaria* (including the idealised diploblastic nematocyst bearing coelenterates) and *Phylum Ctenophora* (including the triploblastic coelenterates without nematocysts).

SUMMARY

1. Members included in this phylum show the humble beginning of tissue-grade of organisation.

2. All members are strictly aquatic and most of them are marine.

3. Adults exist either in polyp or medusa forms.

4. Many members of this group exhibit "Polymorphism".

5. A single aperture, i.e. mouth is present.

6. Cnidoblasts are monopoly of this phylum.

7. Extracellular digestion is followed by intracellular digestion in this group.

8. Many members are instrumental in the formation of coral islands.

CHAPTER 12

Phylum Ctenophora

In the history of metazoan evolution, the ctenophores stand a step ahead of the cnidarian coelenterates by having a low grade triploblastic construction. Like the cnidarian coelenterates, they possess radial symmetry (Fig. 12.1) and coelenteron but lack the definite organ systems. But the presence of eight meridional comb-plates, collenchyme containing amoebocytes, connective tissue fibres, muscle cells developing directly from the mesenchymal cells between the ectoderm and endoderm; advanced condition of the digestive system and the presence of an aboral specialised sense organ indicate a higher grade than that of other cnidarians.

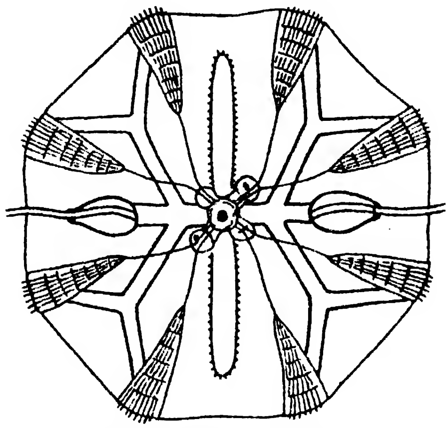


Fig. 12.1. Aboral view of a typical ctenophore showing radial symmetry and eight comb-plates.

IMPORTANT FEATURES

The phylum Ctenophora derives its name from two Greek words, *Ktenos* = comb + *phoros* = bearing. This phylum includes about 80 species of ctenophores. They are characterised by having: (1) Biradially (radial + bilateral) symmetrical body without nematocysts. (2) A gelatinous ectomesoderm containing mesenchymal muscle cells. (3) Eight meridional rows of ciliary plates are present. (4) A specialised aboral sensory organ is present. (5) There are peculiar adhesive cells in the tentacles. (6) Skeleton is lacking. (7) Development is of mosaic type and a distinctive cydippid larva occurs in the life-cycle. (8) They are exclusively marine and are planktonic in habit.

OUTLINE CLASSIFICATION

The phylum Ctenophora is divided into two unequal classes: *Tentaculata* and *Nuda*. The class Tentaculata includes 4 orders: (1) *Cydippida*, (2) *Lobata*, (3) *Cestida* and (4) *Platyctenea*. The class Nuda has only one order: *Beroida*.

Example of the Phylum Ctenophora—*HORMIPHORA*

The basic plan of the ctenophores can be best illustrated with reference to the generalised genus, *Hormiphora. Hormiphora plumosa* is found in the Mediterranean. Its closely allied genus, *Pleurobrachia* is found all over the world as a common pelagic form. In the present text the genus *Hormiphora* is described as a typical representative of the phylum. It is a typical example of Ctenophora which includes variety of forms. Due to diverse adaptive radiation, the different members of this group exhibit wide structural variations. Despite such diversities, the basic organisation remains the same in all the cases. All the ctenophores have transparent gelatinous bodies and are commonly known as "Comb-jellies" because of the presence of comb-like plates on the body. These plates are of paramount significance because the phylum owes its name to these structures.

Structure. Hormiphora has a pear-shaped body measuring 5–20 mm in diameter (Fig. 12.2A). They are pelagic

and are found in the Mediterranean sea. Mouth is situated at the centre of the oral pole and the opposite pole is occupied by a complicated and characteristic sense organ usually designated as the aboral sense organ. This sense organ is a modified statocyst and acts as an organ of equilibrium (Fig. 12.2B). The sense organ which is enclosed within a transverse dome bears a concavity or depression which is internally lined sith tall-ciliated ectodermal cells. Four very long S-shaped tufts of cilia (*balancers* or *springs*) are inter-radially located and arranged at equal distance within the depression. Two slender ciliated areas, called the *polar plates* are transversely arranged within the depression. The balancers project upward and meet to support a rounded mass of calcareous spherules (*statolith*). A pair of ciliated furrows pass to swimming plates from the base of each balancer.

The surface bears eight equidistant meridional *swimming-plates* or *costae* or *comb-ribs* each of which is composed of transverse row of long cilia. A pair of very extensible, long and solid tentacles bearing a row of lateral branches are present on the two sides of the broader end. The bases of these two tentacles are encased by sheath within which they can be retracted. The tentacles are composed of a central core which remains covered by ectoderm consisting largely of adhesive cells, called *colloblasts* (Fig. 12.3A).

Each colloblast develops from a single cell with its nucleus modified into straight filament. The colloblast has a dorsal convex surface and contains numerous

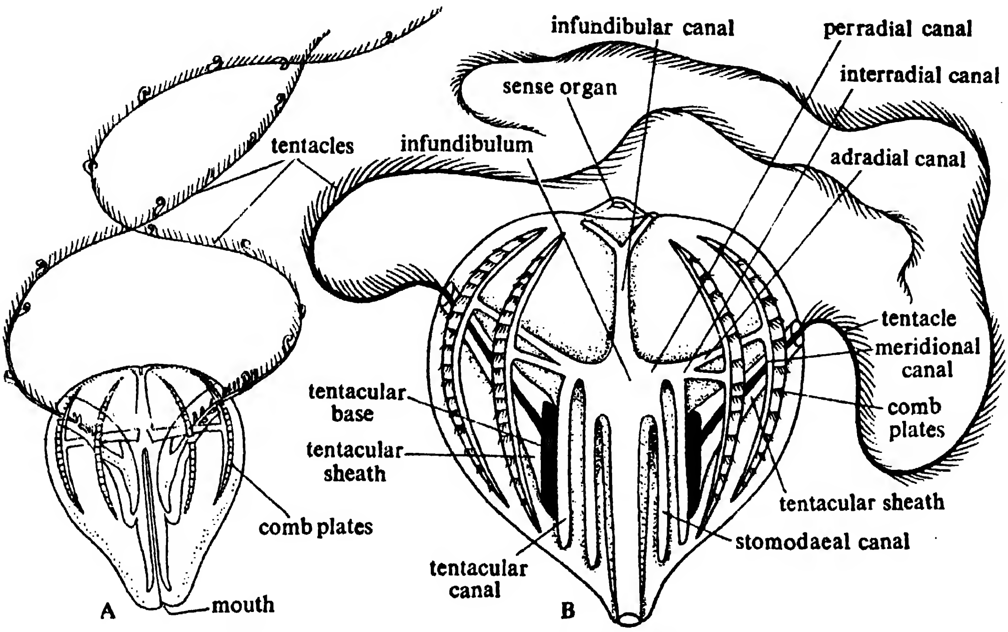


Fig. 12.2. A. External view of *Hormiphora* from a side. B. Diagrammatic view of *Hormiphora* showing inner details. (after various sources).

small papillae which can adhere to any object. The inner side is produced into a spirally coiled filament around the straight nuclear filament. These filaments extend up to the muscular axis of the tentacle.

Histology. Ectodermal cells are cuboidal or columnar in shape and are ciliated in certain regions. These cells are interspersed with numerous gland cells and sometimes certain pigment granules or branched pigment cells (*melanophores*) are also present. The sensory cells are of two types (Fig. 12.3C):

(*i*) One type bears several stiff bristles and

(*ii*) the other type is with a single stout bristle.

The so-called mesoglea is designated as the *collenchyma*. The collenchyma is interpreted as the ectomesoderm and consists of a gelatinous substratum containing cells, connective-tissue fibres and muscle

fibres. All these components are ectodermal in origin, except the muscle fibres which are independent cells arising by the direct conversion of the amoeboid cells. The muscles are elongated smooth fibres disposed longitudinally and circularly.

two *ad-radial canals*. Each ad-radial canal opens within a meridional canal which runs beneath the comb-plate.

Nervous system. The nervous system is much diffused and consists of a general

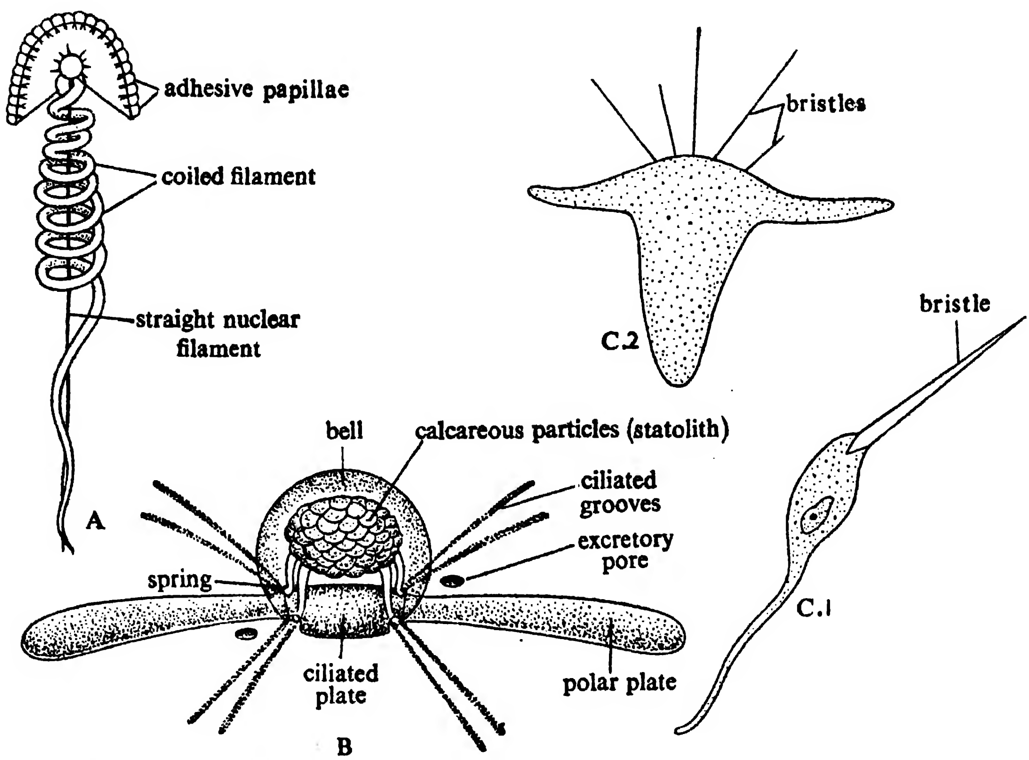


Fig. 12.3. A. Single colloblast of *Hormiphora*. (after Parker and Haswell). B. Statocyst of *Hormiphora*. (after Parker and Haswell). C. Sensory cells of *Hormiphora* (1) With single bristle, (2) With many bristles. (after Hyman).

Gastrovascular or Enteric system. The mouth leads into *pharynx* or *stomodaeum* which has internal ridges. The stomodaeum opens into a cavity known as the *stomach* or *infundibulum* from which arises the following canals of the coelenteron (Fig. 12.2B).

Infundibular canal. It runs upwards up to the aboral pole where it breaks into four small branches of which two open on the surface by the excretory pores and the other two are blind.

Per-radial canal. Two canals, one in each direction, extend along the transverse plane of the body. Each per-radial canal sends (*a*) one *stomodaeal canal* along the stomodaeum, (*b*) one *tentacular canal* in the tentacle and then divides into (*c*) two *inter-radial canals*, each of which subdivides into

subepithelial nerve plexus with multipolar ganglionic cells and neurites throughout the surface.

Reproductive system. Both sexes are present in one individual. Gonads are situated in the wall of the meridional canals as continuous or discontinuous bands. Originating from the endoderm, the matured gametes are discharged into the canals and finally escape through mouth. Fertilisation is external.

Development. Developmental history of Hormiphora is not well known but the following events as observed in other forms of Ctenophora (particularly in *Callianira*) will give the idea of development (Fig. 12.4).

Zygote gives rise to four blastomeres by two meridional cleavages (Fig. 12.4A).

The third cleavage is nearly vertical, resulting in a curved plate of eight cells, arranged in two rows (Fig. 12.4B). The eight blastomeres divide twice along the horizontal plane and give rise in each time eight small cells (*micromeres*) and eight larger cells (*macromeres*) (Fig. 12.4C). The micromeres are the source of ectoderm and the micromeres give rise to endoderm in due course. Micromeres undergo rapid division and proliferate as a wreath of smalls cells over the macromeres which ultimately grow down as a one-layered sheet. Invagination starts and gastrulation goes on by combined processes of emboly and epiboly (Fig. 12.4E). Micromeres cover the embryo to become the ectoderm (Fig. 12.4F), four interradial bands of small rapidly dividing cells become noticeable which differentiate into comb-rows. Ectoderm at the oral pole invaginates extensively to form stomodaeum from which gastrovascular cavity arises by active endodermal outgrowth. Biradial symmetry persists throughout the development.

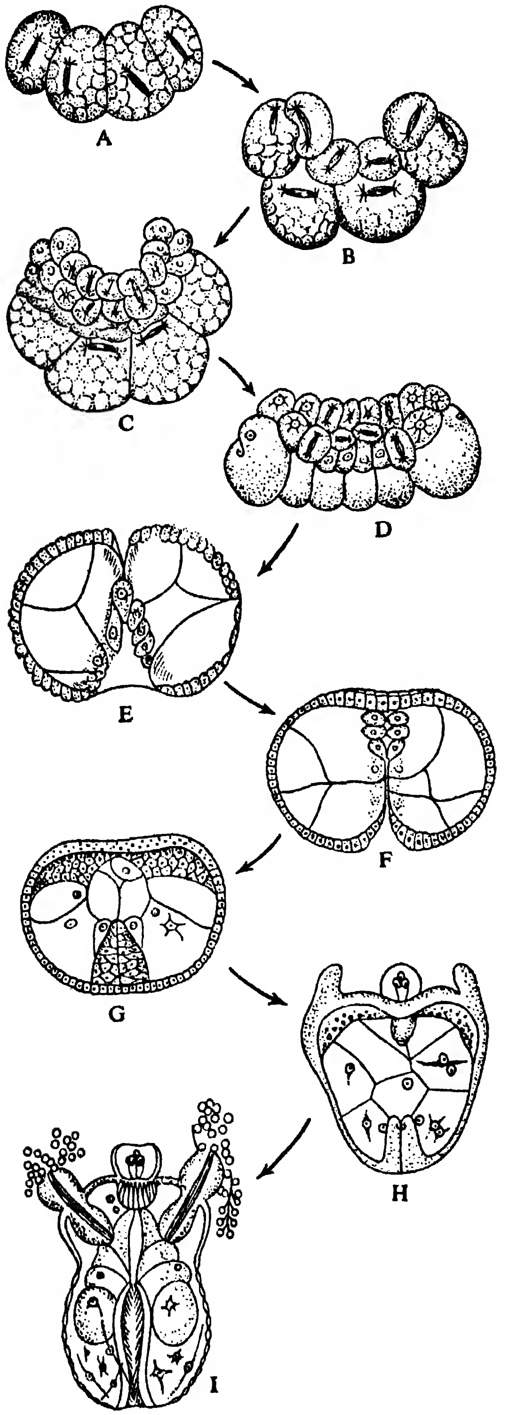


Fig. 12.4. Development of a Ctenophora. A–D. Show only one half. E–I. Sectional view (after Parker & Haswell).

CLASSIFICATION

The phylum Ctenophora is classified into two classes: Tentaculata (Micropharyngea) and Nuda (macropharyngea). The scheme of classification is based on the plan outlined by L. H. Hyman in her book "The Invertebrates: Protozoa through Ctenophora", Vol. I.

CLASSIFICATION IN OUTLINES

Phylum **Ctenophora**

Class: **Tentaculata or Micropharyngea**

Order 1: *Cydippida*, e.g. *Hormiphora*, *Pleurobrachia*.

Order 2: *Lobata*, e.g. *Deiopea*.

Order 3: *Cestida*, e.g. *Cestus*.

Order 4: *Platyctenea*, e.g. *Ctenophora*, *Tjalfiella*.

Class: **Nuda (Macropharyngea)**

Order 1: *Beroida*, e.g. *Beroe*.

CLASSIFICATION WITH CHARACTERS

Phylum **Ctenophora**

The phylum includes the pelagic ctenophores having no polyp stage. The cilia are retained throughout life as the locomotor organs. Presence of eight meridional comb-plates, an aboral sense organ, colloblasts and mesenchymal muscle cells are some of the peculiar features. The phylum embraces two classes:

Class: Tentaculata or Micropharyn-

The members of this class possess tentacles which are usually two in number. The class is divided into four orders :

Order 1: *Cydippida* (*Cydippidea* or *Cydippea*)

The body is round or oval in form. Two branched tentacles retractile into sheaths are present. The meridional canals are unbranched. Examples: *Hormiphora* and *Pleurobrachia*, *Lampetia*, *Callianira*.

Order 2: *Lobata*

The bases of the two principal tentacles are devoid of sheath and numerous non-retractile lateral tentacles are present. Two very large oral lobes are present. Examples: *Deiopea*, *Bolina*, *Leucothea*.

Order 3: *Cestida* (*Cestoidea* or *Cestidea*)

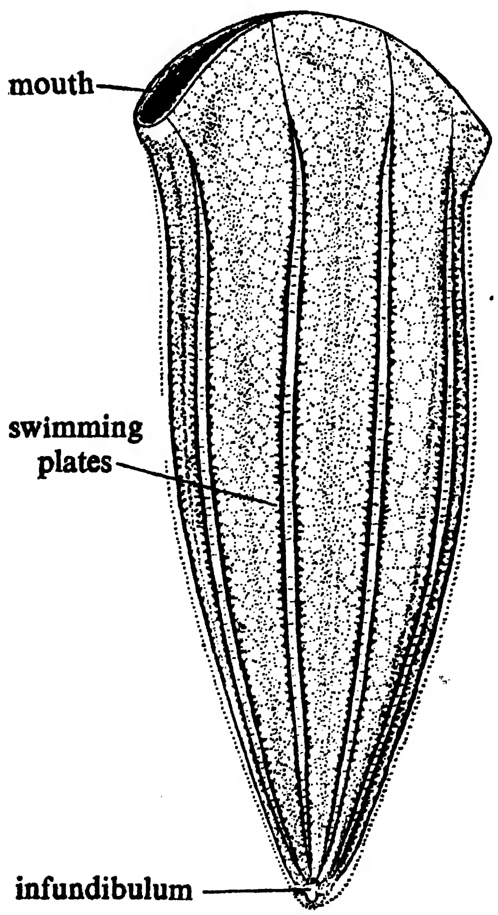


Fig. 12.5. *Beroe*. An example of Ctenophora. Note that tentacles are absent.

The body is extremely compressed in the sagittal plane to form a band-like appearance. Four of the eight meridional comb-plates are rudimentary. The two main tentacles are reduced. Examples: *Cestus*, *Velamen*.

Order 4: *Platyctenea*

The body is flattened and is modified for creeping movement. The comb-plates are restricted only in the larval stage. Examples: *Ctenoplana*, *Tjalfiella*, *Coeloplana*.

Class: Nuda or Macropharyngea

The representative of this class lacks tentacles. This class includes only one order.

Order 1: *Beroida*

The mouth is very wide and the gullet occupies the greater portion of the interior of the body. The meridional canals are produced into a complex system of anastomosing branches. The sole genus of the order is Beroe (Fig. 12.5). Beroe is available in all seas and measures about 20 cm. in height.

GENERAL NOTES ON CTENOPHORA

HISTORY. The ctenophores are recognised since 1671. Linnaeus placed two ctenophores under his group *Zoophyta*. Eschscholtz (1829) was the first Zoologist to recognise the group *Ctenophora*. Since then the ctenophores were included under the phylum Coelenterata along with echinoderms and sponges. Leuckart (1847-1848) separated the coelenterates from the echinoderms but the sponges and ctenophores were included under it. Vasmaer (1877) separated the sponges from the Coelenterates. Since Vasmaer it was the usual convention to include the Ctenophores under the so-called phylum Coelenterata. Hatschek (1889) removed the ctenophores and placed them under a separate phylum Ctenophora.

AFFINITIES AND SYSTEMATIC POSITION OF CTENOPHORA

In the field of taxonomic zoology, Ctenophora, for a long time, occupies a very important place. The importance is primarily due to its peculiar anatomical organisation. Martens (1671) first discovered Ctenophora. Leuckart (1847–1848) included the sponges amongst the ctenophores. But Hatschek (1889) gave a separate status to ctenophores as a group.

The ctenophores bear many characters of the Cnidarians, but it differs considerably from the other members of the phylum Cnidaria. This group has also some similar features with different animals of diverse phyla, which will be discussed here to judge its systematic position. Following features include them within phylum Cnidaria:

Cnidarian features

1. Possession of basic radial symmetry.
2. Lack of coelom.
3. Presence of gelatinous mesoglea.
4. Presence of ramified coelenteron.
5. Presence of diffused nerve network.
6. Presence of statocyst as sense organ.
7. Absence of organ systems.
8. Different parts of the body are arranged along an oral-aboral axis.

But the Ctenophora differs widely from the cnidarians by the possession of meridional comb-plates, lack of nematocysts, possession of adhesive cells (colloblasts), higher and complicated organization of the digestive system, determinate type of development, direct development of muscle cells from the mesenchyme and retention of cilia as locomotor organs in adult.

Relationship with Hydrozoa

WITH CTENARIA (ANTHOMEDUSA)

Similar features

(1) Presence of two tentacles, situated at opposite per radii, each is provided with a deep pouch at its base, resembling closely the tentacular sheath of Hormiphora. (2) Presence of eight radial canals formed by the bifurcation of four inter-radial pouches of the stomach. (3) The subumbrellar cavity of the *Ctenaria* can be homologised with the stomodaeum of Hormiphora.

Dissimilar features

(1) The gullet of Ctenophora is ectodermal in origin.

(2) The tentacles of Ctenaria have no muscular base.

(3) The development of gonad is different. The gonads develop from manubrium in Ctenaria but in Ctenophora gonads develop from meridional canals.

(4) Absence of the characteristic aboral sense organ in Ctenaria.

WITH HYDROCTENA (NARCOMEDUSA). *Hydroctena*, a trachyline medusa, shows close resemblances with Ctenophora. The resemblances are:

(1) Possession of two tentacles with sheath located between the margin and apex of the bell.

(2) Presence of aboral sense organ in Hydroctena can be compared with that of Ctenophora.

But the presence of swimming-plates in Ctenophora and the presence of velum in Hydroctena remain as important differences to visualise a close relation among them.

Relationship with Actinozoa

Actinozoa exhibits some resemblances with the ctenophores. Transverse sections of the embryos in both of them are similar. The stomodaeum in both can be homologised, the gonads are endodermal in origin and the mesoglea is cellular in both. But the presence of aboral sense organ in Ctenophora and the presence of hollow tentacles in Actinozoa are the principal differences existing between them. So due to the presence of vast structural diversities between them, no relationship can be advocated though it was greatly emphasised by T. H. Huxley.

Relationship with Scyphozoa

The scyphozoans have long been looked upon as to be related to Ctenophora. Because in both of them the following features are common: (1) The stomodaeum is similar. (2) Gametes are endodermal in origin. (3) Coelenteron is four-lobed. But due to the presence of four characteristic oral arms, numerous marginal tentacles and the absence of meridional comb-plates in Scyphozoa, the aforesaid homologies cannot be established.

Relationship with Sponges

Many authors tried to establish the sponges as to be closely related to Ctenophora. They put forward the following points to support their contentions:

(1) The large central cavity and the osculum of sponges correspond to the coelenteron and mouth of Ctenophora respectively.

(2) Absence of well-formed mesoderm in both.

(3) Simpler organisation in both.

But closer examination reveals that these two groups are quite widely apart. The points of differences are:

(1) Developmentally the osculum of sponges does in no way correspond to the mouth of Ctenophora.

(2) Presence of inhalant pores and peculiar collar cells in sponges are lacking in Ctenophora.

(3) Absence of colloblasts in sponges.

(4) Absence of specialised nervous and sensory structures in sponges.

The above differences are sufficient to separate the two groups from each other, though the above relationship is emphasised by Leuckart and some other authors.

Relationship with Platyhelminthes

The idea that Ctenophora gave rise to certain bilateria (Polyclad) has been supported by many Zoologists. *Platyctenea* has been considered to be a connecting link between Ctenophora and the bilateria. Besides, Ctenophora in general shows many structural similarities with the Platyhelminthes and particularly with the Turbellarians. The similarities are:

(1) General ciliation of the body.

(2) The dorsal polar nerve of *Turbellaria* can be compared with the statocyst of Ctenophora.

(3) Origin of the so-called mesoderm is more or less similar.

(4) Primary locomotor organs in the larva (Muller's larva) consist of eight ciliated ridges of ectoderm which can be compared with the Ctenophoran meridional comb-plates.

(5) Ctenophora exhibits both radial as well as bilateral symmetries.

The view that the primitive bilateria have evolved through Platyctenea has not been accepted. Because a thorough examination of the Platyctenea reveals that it is a ctenophore which has become extensively modified for sessile habits. It can further be suggested that Platyctenea is a tissue-grade diploblastic animal, whereas Polyclad is an organ-grade triploblastic form. Further, it can be said that amongst the Platyhelminthes, the Acoela is the most primitive group and not the Polyclads. The Ctenophora, on the other hand, shows no close similarity with the Acoela.

Relationship with Nemertines

The larval form of Nemertine (*Pilidium* larva) shows some similarities with ctenophores. In Pilidium larva locomotion is performed by lobed bands of cilia. The aboral end on the body contains a cup-like sense organ. But these similarities are of no use as the anatomical organisation in both shows many diversities. Ctenophores lack mesoderm proper. Paired tentacles with basal musculature are present in Ctenophora. The aboral sense organ in both differs widely. The similarities may best be explained as to be due to distant convergence and perhaps with no phylogenetic significance.

Phylogenetic status

The proper status of Ctenophora still remains uncertain and offers a problem for further studies. It is now more or less universally accepted that the group separated out very early from the "trachyline stem" at the time when other groups of the cnidarians originated. It cannot, however, be denied that the Ctenophora presents certain structural features which resemble more to the forms with bilateral symmetry. Considering all the features of ctenophores, it has now been proposed to treat these coelenterate-like animals under a separate phylum. As regards the relationships of different groups of Ctenophora, it can be suggested that both *Cestidea* and *Lobata* have been derived from Cydippid-like forms because during development both of them pass through a stage closely resembling the *Cydippidea*.. *Beroidea* is a highly organised form which may have arisen from some tentaculate form. Regarding Platyctenea, whether they are primitive forms or specially modified is a question yet to be answered.

SUMMARY

1. The ctenophores are characterised by having biradially symmetrical bodies, eight meridional comb-plates on the body, mesenchymal muscles, an aboral sense organ and adhesive cells.

2. The ctenophores were included with the nematocyst bearing coelenterates under a common phylum Coelenterata by older zoologists because of presence of coelenteron. But the recent trend has given the ctenophores a separate phyletic status.

3. The phylum ctenophora includes about 80 species which are categorised into two unequal classes—Tentaculata and Nuda. The Tentaculata comprises of 4 orders: *Cydippida*, *Lobata*, *Cestida* and *platyctenea*. The class Nuda includes a single order: *Beroida*. The examples of the phylum are: *Pleurobrachia*, *Bolinopsis*, *Cestus*, *Ctenoplana*, *Beroe*, etc.

4. The phylogenetic status of Ctenophora is controversial. They have possibly diverged from the early trachyline stem form which holds the ancestry of Cnidarians.

CHAPTER 13

Phylum Platyhelminthes

Multicellular condition has given rise to a two-layered orientation. In cnidarians the body is made up of different types of cells oriented in two distinct layers, the ectoderm and endoderm separated by a non-cellular partition—the mesoglea. In cnidarians there is cell-specialisation but further histological differentiation is lacking. The evolution of a third layer of cells, *mesoderm*, between ectoderm and endoderm has opened up further possibilities of increase in size and structural complexities. Animals built on this three-layered foundation have been designated as *Triploblastica* (Fig. 13.1). Even the simpler triploblasts, like Platyhelminthes show evolutionary achievements over the diploblasts in having definite organs or systems of organs which are concentrated and localised in definite regions of the body.

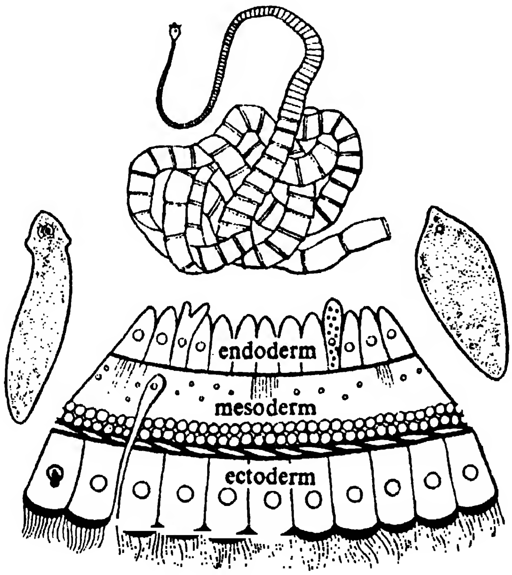


Fig. 13.1. Three representatives of Platyhelminthes with a part of their body wall to show triploblastic organisation.

IMPORTANT FEATURES

1. Platyhelminthes are flat, triploblastic, acoelomate and bilaterally symmetrical animals. 2. Metameric segmentation and skeletal structures, in any form, are absent. 3. Definite anus, circulatory and respiratory organs are also absent. 4. Differentiation of the anterior end as head in them is a foreshadow of the things to come. 5. Body space in them is packed with parenchyma. 6. Majority of platyhelminthes are internal or external parasites in other higher animals, while many are free-living. 7. Platyhelminthes present a simpler type of triploblastic organisation. Here mesoderm is not splitted into *somatic* and *splanchnic* layers. Mesoderm gives rise to muscular and reproductive systems and produces, a special kind of tissue, parenchyma, to fill up the body space.

CLASSIFICATION IN OUTLINES

Phylum Platyhelminthes includes three classes, *Turbellaria*, *Trematoda* and *Cestoda*. The turbellaria includes most of the free-living flatworms, while trematoda and cestoda cover important parasitic forms.

EXAMPLE OF THE PHYLUM PLATYHELMINTHES—*PLANARIA* (*DUGESIA*)

Habit and Habitat. *Planaria* is a member of the class *Turbellaria* and is free-living. Planarians are inhabitants of cool, clear and permanent water and cling to the undersurfaces of leaves, logs, rocks sub-

merged in streams, ponds and lakes. They live in damp surroundings as their bodies are not protected against dessication. They always avoid light and rest on the under-surfaces of objects during daytime either singly or in groups. After dark they become active. The distribution of Planaria is world-wide.

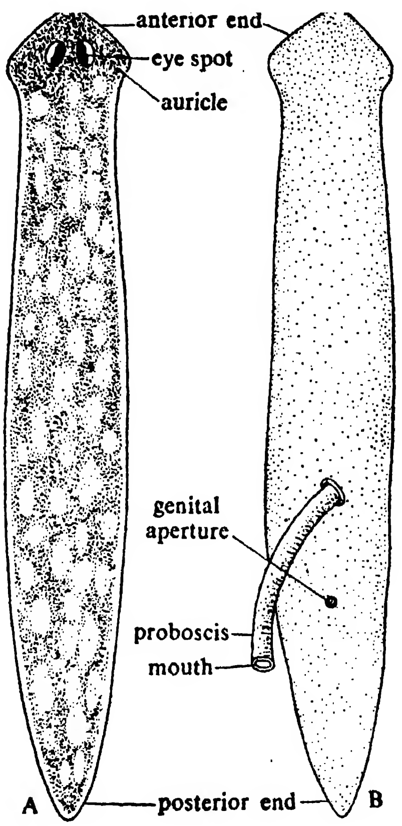


Fig. 13.2. External features of *Planaria* (after Bloom and Krekeler).

A. Dorsal view. B. Ventral view. Note that pharynx is shown in everted condition as proboscis.

Structures. A full grown Planaria is under 50 mm in length. Body is flattened, thin, leaf-like and oval in outline (Fig. 13.2). They exhibit bilateral symmetry and polarity is well-marked. There is no well-formed "Head" but a definite *anterior end* with organs of special sense is recognised. The anterior end is always directed forward in the direction of movement and it is broader than the other end, i.e. the *posterior.* The body surface next to the substratum during locomotion is the *ventral* side and the uppermost surface is *dorsal* side. The anterior region is triangular with small lateral projections and bears a pair of black *eye spots* on the mid-dorsal line. Auricular organs are lodged in these projections. The mouth is situated in the mid-ventral surface. Sexually mature worms have a single genital aperture situated below the mouth. Excretory apertures are minute and situated on the dorsal surface. The colour, though variable in different species, is usually grey, red, brown or black.

Body wall. The outer covering of the body is epidermis which is ciliated on the ventral surface and contains many scattered sensory and gland cells (Fig. 13.3). In the epidermis there are many rod-shaped hyaline structures called *rhabdites.* The rhabdites, when discharged come in contact with water swell, stick together and form a froth. The exact role of the rhabdites is not known and it is presumed that they help in capturing food particles and also render protection to the body. Just beneath the epidermis there is a thin *basal membrane* which serves as a partition between

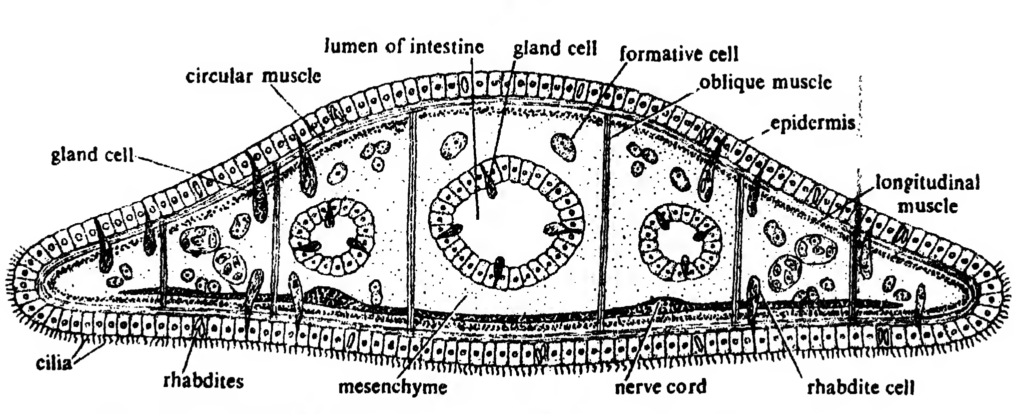


Fig. 13.3. Transverse section of *Planaria* passing through epipharyngeal region.

epidermis and underlying muscle layers. The basal membrane is stratified and bears pigments below. Beneath the basal membrane the muscle fibres are arranged in two layers. The fibres of the outer layer are arranged in a circular manner around the body and are called *circular muscles* while the inner fibres lie parallel to the longitudinal axis of the body and are called *longitudinal muscles*. In addition, a third layer of *oblique fibres* arranged in vertical fashion is also encountered. The longitudinal muscles of the ventral side are more strongly developed than their counterparts on the dorsal side. Lying between the gut and muscular layers of the body wall is the *parenchymatous tissue*. These are loose connective-tissue cells, parts of which remain in formative state and can metamorphose into specialised cells. They help in regenerating lost or damaged body parts. They also undertake vascular function by conducting food and other metabolic products from one part of the body to another part. Embedded in the parenchyma there are many *gland cells*.

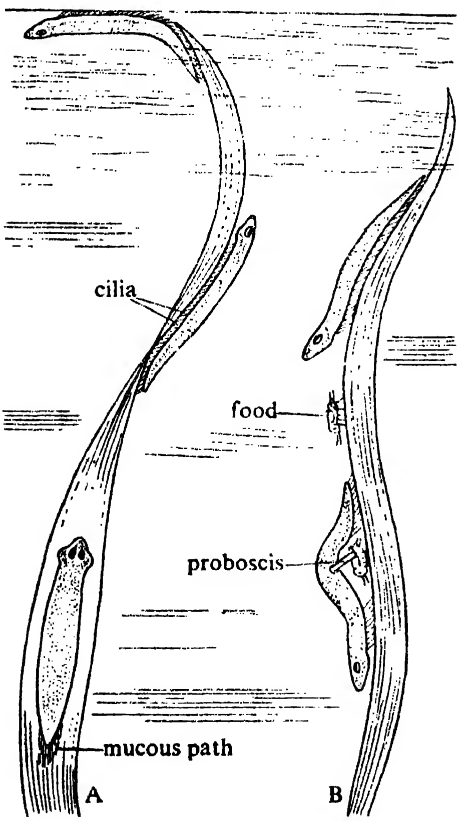


Fig. 13.4. Locomotion (A) and feeding (B) in *Planaria* drawn on the leaves of aquatic plant (after Elliott).

Locomotion. Planaria lives in water, but it does not swim. Locomotion is performed usually by *gliding* (Fig. 13.4A). During gliding, the anterior end remains forward and slightly raised. The backward stroke of the cilia on the ventral surface helps the animal to move forward over a slime track. The slime track is produced by the secretion of glands in the body wall. Sometimes the animal also *crawls*. This is performed by muscular movements. Contraction of circular and dorso-ventral or oblique muscles causes elongation of the body. The anterior end is then fixed firmly on the substratum by mucus and the posterior part is drawn up by the contraction of longitudinal muscles. *Turning* and *twisting* movements are also shown by planarians. This is done by different action of total muscle groups.

Digestive system. The digestive system consists of well-developed alimentary canal with only one opening called mouth (Fig. 13.2B). The *mouth* is situated in the mid-ventral line of the body and leads through a small buccal cavity into the pharynx which is cylindrical, muscular and thick-walled (Fig. 13.5A). The pharynx can be everted as a proboscis and can be extended to some length. In retracted condition the pharynx remains enclosed in a muscular sheath. The pharynx opens into the *intestine*. The intestine is divided into three main branches. One of these branches runs forward along the middle line and the other two run backwards. Each of those main branches gives off lateral ramifying branches and as a result, the whole intestine forms a network occupying the major part within the body. All the branches end blindly and there is no *anal aperture*. Columnar epithelial cells line the inner walls of the intestine. The histological structure of the pharynx is interesting. It is lined with the nucleated parts of the ciliated epithelial cells of the body wall. These nucleated parts invaginate through the basal membrane and muscle layers still having contacts with their own cell bodies by protoplasmic bridges.

Mechanism of feeding. Planarians feed on dead or living organisms, mostly the crustaceans, which are entangled in the secretion of the expelled rhabdites

(Fig. 13.4B). They engulf the food by enclosing it in the everted pharynx or by suction. Digestion is both intra- and extracellular. As there is no anus, undigested food particles are obviously forced out through mouth.

Respiratory system. Planarians are active animals and need supply of oxygen

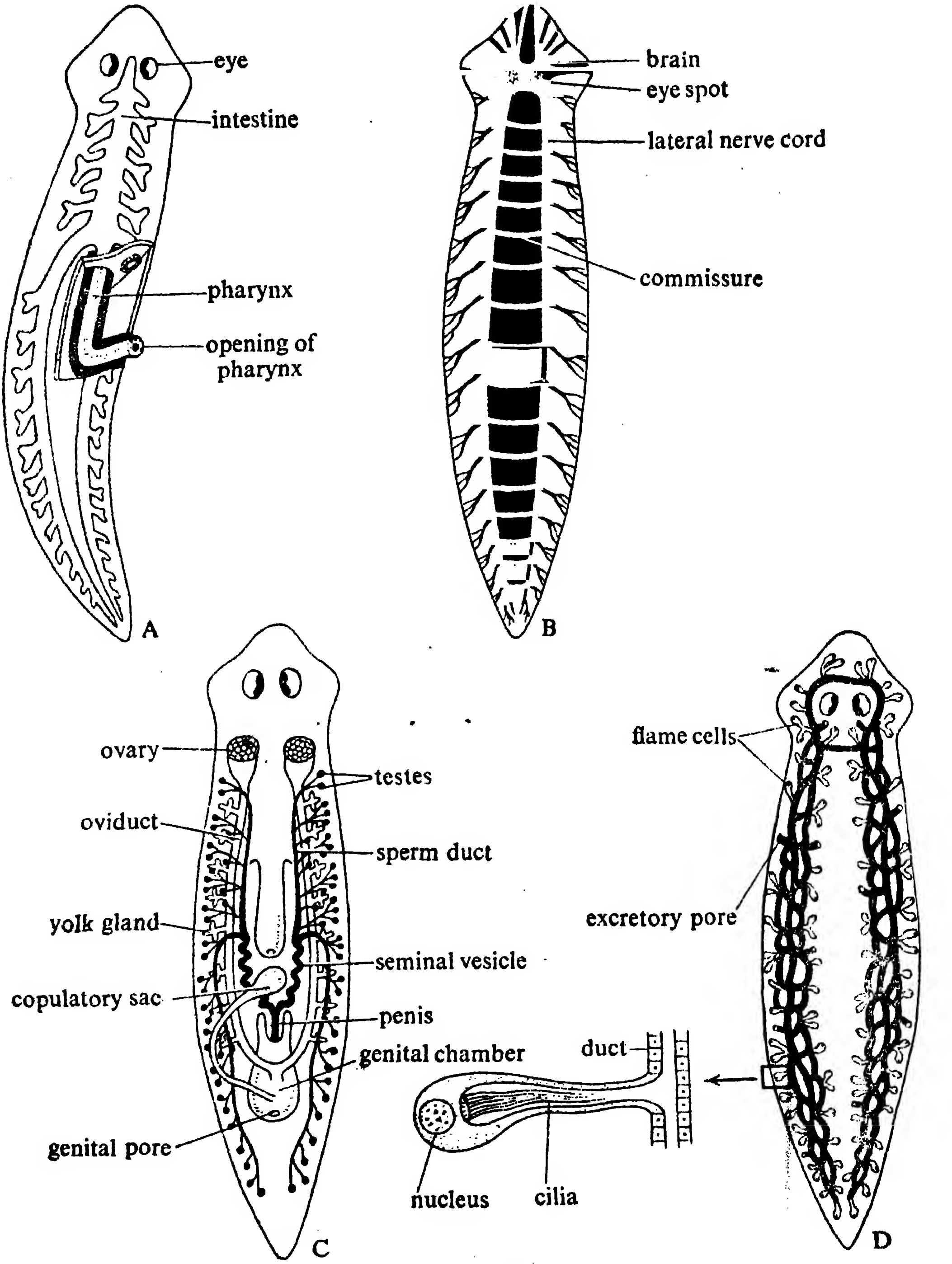


Fig. 13.5. Figures show the different systems of *Planaria* (after Guyer and Lane). A. Digestive system. B. Nervous system. C. Reproductive system. D. Excretory system (Longitudinal trunks are shown in black and one flame cell is enlarged).

and removal of carbon dioxide. There is no special system for this purpose. This gaseous exchange is carried out by the whole body surface, i.e. respiratory exchange is by diffusion.

Excretory system. Excretory system or the system of *water vessels* consists of two pairs of *longitudinal trunks*, right and left, which run through the whole body length (Fig. 13.5D). Each trunk is much coiled and is connected with each other by *transverse vessels* in the anterior region and opens to the outside by means of several pairs of *pores* which are situated on the dorsal surface. The lumen of the vessels is lined by ciliated cells. The trunks give off numerous *branches* within the body. From these branches extremely fine *capillary vessels* emerge. Many of these capillary vessels bear *flame cells* or *flame bulbs* or *paranephridia* at their tips. The flame bulb is a large cell bearing many *cytoplasmic projections*. The *nucleus* is displaced to one side of the cell and the cytoplasm bears secretory droplets and is hollowed out to form a large central cavity which is continuous with that of the capillary vessels. A bunch of *cilia* hangs down into the cavity of the cytoplasm. It is the flickering movement of these cilia that gives the flame bulb its name.

The excretory products in fluid state enter from the parenchyma cells by diffusion. The cilia within the cavity of the cytoplasm beat continuously and keep the fluid circulating. It is also believed that the flame bulb helps in the elimination of excess of water, i.e. they help in osmoregulation.

Nervous system. Planarians possess highly organised nervous system than the diffused nerve-net of cnidarians (Fig. 13.5B). The nervous system consists of a pair of *cerebral ganglia* joined to form a bilobed *brain*. The brain is made up of connecting *transverse fibres* and *nerve cells*. It gives short nerves to the eyes and two longitudinal nerve cords which pass backward. From these nerve cords numerous *transverse* branches are given both to the external and internal parts of the body.

The internal branches often anastomose to form *commissures*. Two types of sense organs, *eyes* and *auricular organs*, are recognised in the planarians.

(1) *Eyes*. They occur as a pair of rounded dark spots on the anterior dorsal surface (Fig. 13.6). The eyes are made up of a

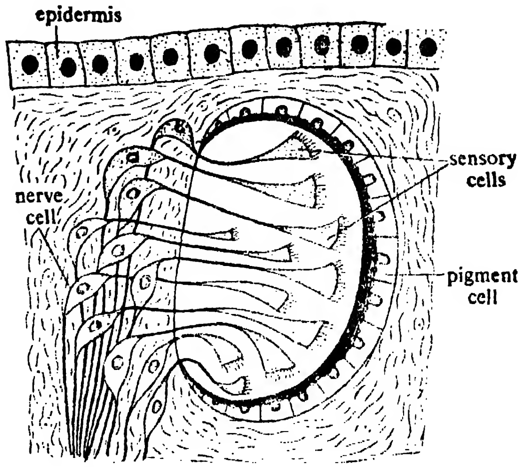


Fig. 13.6. Planarian eye—sectional view (after Kaestner).

cup-shaped *pigment screen*. Inside the cup there are many *sensory cells*. The planarians can make crude discrimination of the direction of light.

(2) *Auricular organs*. A few sensory cells are found to be arranged in groups at the sides of the head. These cells lack cilia and rhabdites and are called *auricular organs*. These organs are responsible for chemical sense.

Reproductive system. Planaria reproduces both *asexually* and *sexually* (Fig. 13.7).

Asexual reproduction. Some planarians reproduce asexually by transverse fission. The worm constricts into two—a little behind the pharynx and each piece grows and regenerates the missing parts. Planarians possess proverbial power of regeneration. In fact any part of the body can grow and develop into a new individual (Fig. 13.8).

Sexual reproduction. Planaria is *hermaphrodite*, i.e. same individual bears male and female reproductive organs (Fig. 13.5C).

(*a*) *Male*. Male reproductive organ consists of *testes*, numerous *vasa efferentia*, a pair of *vasa deferentia* and a *penis*. The testes are numerous, small and round. They are situated on the right and left borders on the body. Each testis is connected to the vas deferens of its side through

a small duct, the vas efferens. The right and left vas deferens unite at the middle of the body and form a *median duct* which passes through the muscular penis. The penis opens into the *genital atrium* which opens to the outside on the mid-ventral line beneath the mouth. The median duct is somewhat swollen at the base of the penis and forms the *vesicula seminalis*. The median canal receives unicellular *prostate glands*.

(*b*) *Female*. Female reproductive organ consits of a pair of small, rounded *ovaries* or *germaria* situated at the anterior end of the body. From each *ovary* there arises one *oviduct*. The two oviducts meet at the posterior and ventral part of the body to form a *common oviduct* which opens into the *genital atrium*. The genital atrium is connected with a median round chamber—the *uterus* and a thick-walled muscular structure—the *muscular sac*. Numerous branching *vitelline glands* open into the oviducts.

Process of sexual reproduction. Though hermaphrodite yet the planarians practise *cross-fertilization*. During sexual reproduction two planarians bring their postero-ventral surfaces together and copulate. Copulation here means mutual exchange of sperms. Sperms from the seminal vesicle of the male system of one are passed onto the

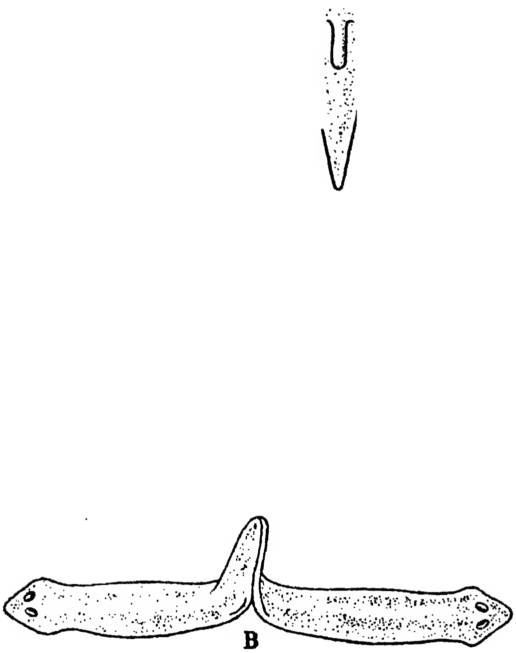


Fig. 13.7. Reproduction in *Planaria*. A. Asexual reproduction by fission (after Buchsbaum). B. Sexual reproduction—mating (after Storer and Usinger).

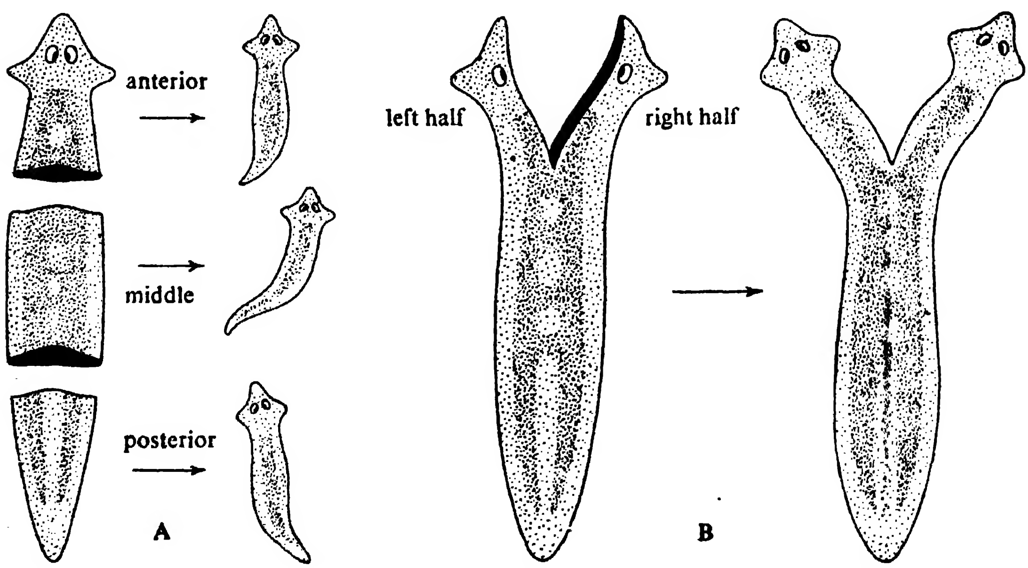


Fig. 13.8. Regeneration in *Planaria* (after Hardin). A. Excised through transverse plane. B. Excised through longitudinal plane.

female genital atrium of the other. The planarians then separate and the sperms migrate to the oviduct to fertilize the eggs. The fertilization is internal. Several *zygotes* together with *yolk cells* later become encased in a capsule or *egg shell* and then the egg shell comes outside the body of the mother. Development is direct and there is no larval form.

Example of the Phylum Platyhelminthes—*LIVER FLUKE*

Habit and Habitat. Liver flukes are typical digenean trematodes. It was reported in the year 1379 and as such is the first described trematode. It lives as an endoparasite in the bile duct of sheep and is scientifically known as *Fasciola hepatica.* The adult flukes are typical parasites of vertebrate animals but one stage of their life history is invariably spent in an invertebrate host—a mollusc. This alternation

Structures. *Fasciola hepatica* is a soft bodied, flattened leaf-like animal and exhibits *bilateral symmetry.* The size varies from about 1·0 to 2·5 cm in length but the width does not generally exceed 1·0 cm. The anterior end has a conical projection—the *head lobe* and at its apex is situated the *oral* or *anterior sucker* perforated by the *mouth.* On the ventral surface, a little behind the head lobe, the *ventral* or *posterior sucker* is situated. It is bigger in size than the anterior sucker. Between the two suckers and close to the posterior sucker there is the *genital opening* through which the *penis* sometimes protrudes. The *excretory aperture* is single and lies at the extreme posterior tip of the body. The *canal of Laurer* opens on the middle of dorsal surface. The body surface is marked by the presence of a number of conical projections—the *spinules* or *papillae* which are extensions of the cuticle surrounding the body.

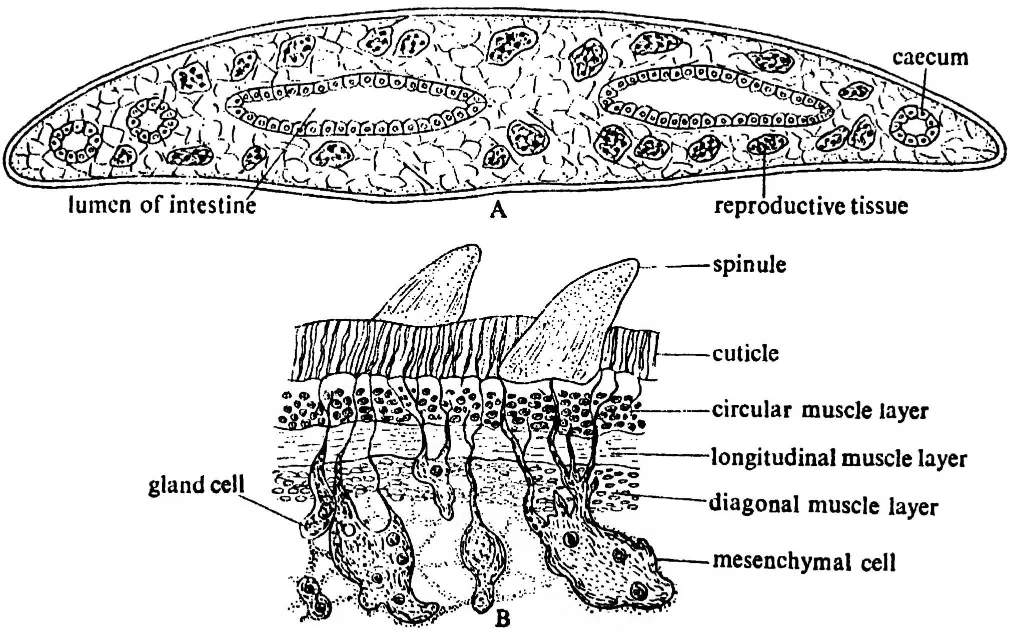


Fig. 13.9. A. Transverse section of liver fluke (after Bloom and Krekeler). B. Magnified view of a part of the body wall in longitudinal section (after Hyman).

of hosts suggests that they have digenetic life histories. The group to which they belong has been named as *Digenea.* Sometimes the adult flukes invade other cattle and man and cause serious loss of human life and domestic animals. The disease caused by the parasites is known as *liver rot.*

Body wall. The architecture of the body wall is peculiar to some extent. In histological sections (Fig. 13.9), it appears that the body wall is made up of a homogenous cuticle (now called epidermis) from which spinules arise. Beneath the *cuticle* there are *circular muscle fibres* followed

by *longitudinal muscle fibres* and *oblique* or *diagonal muscle fibres*. The muscle layers bear underneath a number of unicellular gland cells. These cells open to the outside by long ducts. Interspaces between the organs are packed with parenchyma cells. The *epidermal layer* is absent but many *ectodermal* cells are seen to sink into the parenchyma and are connected to the cuticle by protoplasmic projections (Fig. 13.9B).

Digestive system. The mouth is situated in the middle of the anterior sucker and opens into rounded bulb-like *pharynx* which is muscular and suctorial (Fig. 13.10A). Next to the pharynx is the *oesophagus* which is very short and is followed by the *intestine*. The intestine is bifurcated into two limbs—right and left and runs to the posterior side of the body. Each limb ends blindly and gives off numerous blind branches or *caeca*. The caeca of the inner side are short and simple while those of the outer side are large and branched. Practically every region of the body is traversed by the caeca. The intestine and its branches are very prominent as they remain filled with biliary matter, desquamated epithelium and blood on which the animal feeds. There is no aperture between the intestine and the exterior, i.e. the anus is absent.

Excretory system. The excretory system or system of *water vessels* consists of a median longitudinal *excretory canal* or *protonephridial tubule* which opens to the posterior by means of the excretory pore situated at the posterior tip of the body. From the anterior region of the main canal four *large canals* are given off. Each canal gives repeated *branches*. These branches finally end in fine microscopic vessels or capillaries which enter the inconspicuous *flame cell* or *flame bulb*. The excretory canals normally contain fat droplets.

Nervous system. The nervous system consists of a pair of prominent *nerve ganglia* situated one on either side of the oesophagus (Fig. 13.10B). The ganglia are joined together by a nerve ring around the oesophagus. From the nerve ganglia nerves are given off to the head lobe and to the posterior part of the body. Amongst these posterior nerves a pair become larger and stouter than the rest and run posteriorly as *lateral nerve cords* and bear branches. The presence of a rather well-developed nervous system in Fasciola is

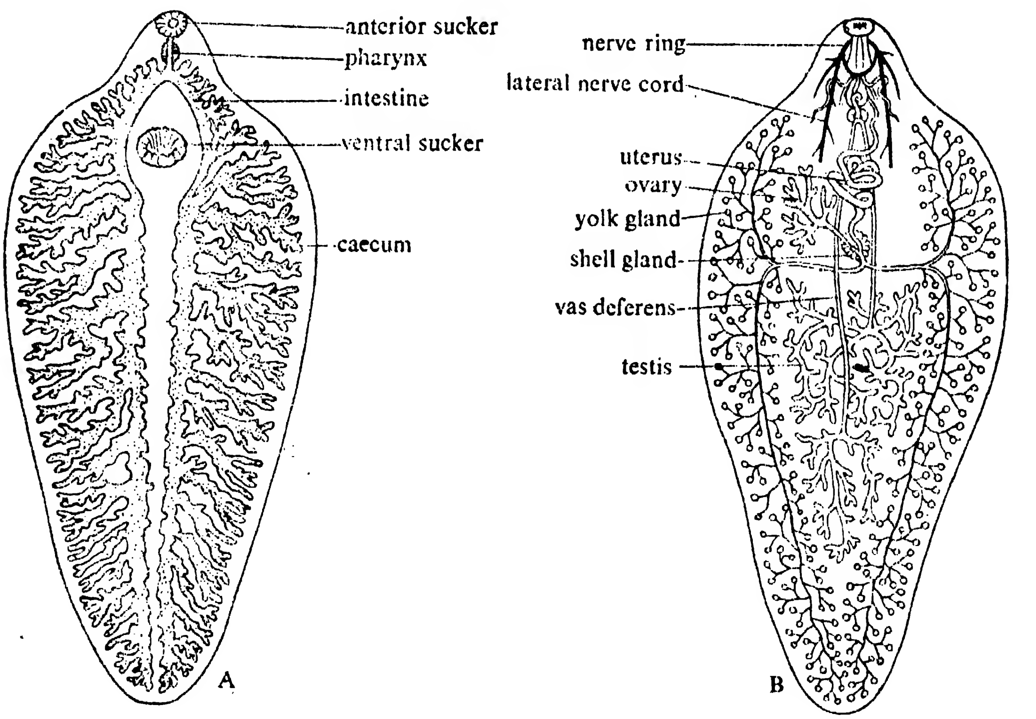


Fig. 13.10. Liver fluke. (A) Digestive system (after Kaestner). (B) Nervous and reproductive systems (major part of the lateral nerve cords is removed).

puzzling because sense organs in them are lacking and the sluggish movement of the animal does not demand a large correlation centre. Absence of sense organs is due to parasitic mode of living.

Reproductive system. Fasciola reproduces sexually and the same individual bears both the sexes (Fig. 13.10B).

Male. Male reproductive system consists of a pair of *testes* which are in the forms of much branched tubules and occupy a major part of the middle region of the body. From each testis is given off a *vas deferens* which runs towards the anterior region. The two vasa deferentia unite and form a median coiled and dilated *vesicula seminalis*. From it a narrow tube—the *ejaculatory duct* leads to the male aperture situated at the tip of *cirrus* or *penis*. The penis opens into *genital atrium*.

Female. The female reproductive organ is a single *ovary* or *germarium*. The ovary is in the form of a much ramified tube situated in the right anterior region and above the middle line of the body. The tubules of the ovary open into a single median *oviduct*. *Vitelline glands* are numerous, minute and round and open by small ducts into a large duct. There are two such ducts. The two ducts meet and form a *lateral vitelline duct* which runs transversely and opens into a small chamber called *yolk reservoir*. From it comes out a *median vitelline duct* which opens into the oviduct. Around this junction there are groups of unicellular *shell glands* or *accessory female glands* which open by small ducts into the lumen of the oviduct. The lumen of the oviduct at this region is dilated and called *ootype*. The *uterus* is a wide convoluted tube formed by the oviduct and the median vitelline duct and it opens in the *genital atrium* near the base of the *cirrus*. A canal, termed *Laurer's canal* leads from the junction of oviduct and median vitelline duct and opens externally on the dorsal surface. The role of the Laurer's canal is to throw out excess yolk cells and possibly the eggs.

The common *genital aperture* is situated on the mid-ventral line between the suckers and close to the ventral sucker.

Life history. Fasciola is hermaphrodite but cross-fertilization is the rule. Pairing flukes with the penis of one introduced into the uterus of the other have been observed. Copulation through *Laurer's canal* has also been reported. The completion of life cycle (Fig. 13.11) depends upon the transference of the parasite from one host to the other through an intermediate host. The eggs become fertilized in the lower part of the oviduct and then pass onto the uterus. Each egg receives a fair amount of *yolk* from the yolk cells and vitelline secretions and finally becomes enclosed in a proteinaceous *shell* or *capsule* secreted by the *shell glands*. The shell becomes hard when it enters the uterus. The hardening is caused by the action of quinone. One pole of the egg-shell bears a small lid or *operculum* for the exit of the future larva. The egg thus becomes complete and comes out of the uterus into the bile duct of the host. From the bile duct it is carried to the intestine and finally gets out of the body along with the faeces of the host. The egg can survive if only it falls on damp soil.

Miracidium. Development within the eggs ceases with the emergence of *miracidium* larva through the operculum of the egg. The miracidium is conical in appearance and bears *cilia* round the body. A distinct *head lobe* or *apical papilla* is situated at the broad end of the miracidium. Behind the head lobe there is a pair of *eyes*. Within the body just below the *epidermis* lie delicate layers of *circular* and *longitudinal muscle fibres*, the *mesenchyme*, one pair of *flame bulbs* with ducts and a sac-like *intestine*. The *germ cells* in blocks are present on the posterior part of the body. The head lobe bears *penetration glands*. The miracidium swims freely in water or crawls over damp surface for some time and dies in case it does not find its second host—the fresh-water snail.

Sporocyst. On meeting the snail (usually *Limnaea truncatula*) the miracidium bores into it by the operation of the penetration glands and reaches the internal organs, specially the *pulmonary sac*. It metamorphoses into *sporocyst* by casting off the ciliated covering. The sporocyst is elongated in appearance and its internal cavity is lined with cells. It also contains germ cells. The germ cells and the lining cells are budded off which undergo segmentation and produce *redia* (First generation).

Redia. A redia is provided with *mouth*, *pharynx* and a simple *intestine*. It bears a circular ridge or collar a little behind the anterior end. It is formed by the bulging of body wall. A redia is elongated in

appearance and bears a pair of short muscular projections at the posterior side. Many germ cells are found in the body cavity. These germ cells in winter months may give rise to a second generation of rediae. The redia comes out of the sporocyst and migrates to the digestive gland of the snail. The germ cells within the body of redia undergo segmentation and give rise to *cercaria.*

Cercaria. The cercaria is provided with a *long tail* and *oral* and *ventral suckers.* Alimentary canal is well-developed and consists of *mouth, pharynx* and a bifid *intestine.* Paired *excretory tubules* with *flame cells, germ cells* and *peripheral cyst-forming cells* are also encountered. The cercaria comes out of the body of the snail. It swims for some time and then takes refuge on green leaves. Ultimately the tail is shed

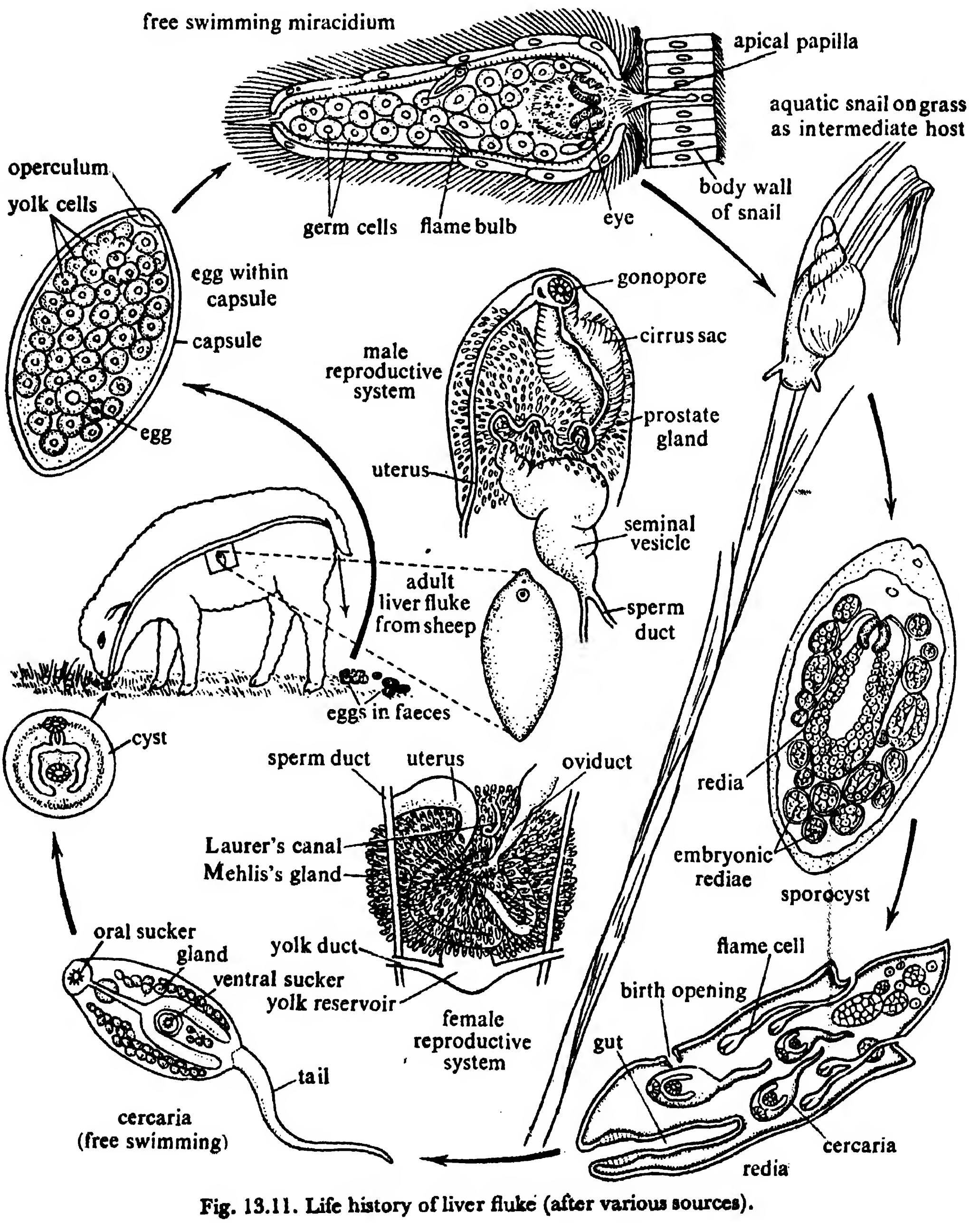


Fig. 13.11. Life history of liver fluke (after various sources).

and it becomes *encysted*. The cercaria in encysted condition is called *metacercaria*.

TRANSFERENCE TO HOST. When the sheep feeds on the infested green leaves, metacercaria enters the gut. The young fluke emerges from the metacercaria in the gut and migrates to the bile duct where it grows rapidly.

EXAMPLE OF THE PHYLUM PLATYHELMINTHES—*SCHISTOSOMA*

Many trematodes live in the venous system of man and other mammals. They are commonly called Blood flukes. They come under the genus *Schistosoma*. The important members under this genus are *S. haematobium*, *S. mansoni* and *S. japonicum*. The anatomy and life history of these three species are very similar. The biology of *S. haematobium* is discussed below.

Geographical distribution. The medically important human blood fluke, *Schistosoma haematobium* has a wide distribution in South Africa and it has been a scourge in Egypt since ancient times. Outside Africa *S. haematobium* occurs in Portugal, Mauritius, Mesopotamia and Madagascar. A few cases have been reported from Bombay (India).

Habit and Habitat. Unlike other trematodes *Schistosoma haematobium* is dioeceous. The males lodge the females in their body folds. The adult flukes are found in the mesenteric branches of portal vein, vesicoprostatic, pubic and uterine plexuses and in the vesical veins. The disease caused by it is called *Schistosomiasis*, the clinical manifestation of which is Haematuria. The larval stages are spent in the intermediate host—the fresh-water snail, *Balinus* (in Africa) and *Planorbarius* in Portugal.

Structure. The males are larger than the females and attain a length of 1–1·5 cm and a breadth of 1 mm. The males are flat while the females are cylindrical. The males possess a gynecophoric canal (Fig. 13.13C) formed by a tube-like ventral infolding of the thin, post-acetabular body margin. The females and males are otherwise structurally almost similar. The oral and ventral suckers are present. In males the ventral sucker is more strongly developed. In females both the suckers are of the same size and weak. The *genital aperture* is located on the ventral surface immediately behind the ventral sucker.

Body wall. The body wall is composed of a homogeneous epidermis (formerly designated as cuticle) bearing backwardly directed *spines* or *papillae*. The spines are found all over the epidermis in males while in females the spines are restricted to the anterior and posterior ends. The epidermis rests on a basement membrane which is followed by circular, oblique and longitudinal muscle fibres. The spaces among organs of the body are filled with parenchyma cells of irregular shape.

Digestive system. The digestive system is similar in both the sexes. The *mouth* is subapical and leads to a funnel-shaped *buccal cavity*. The buccal cavity is surrounded by the oral sucker. The buccal cavity leads to the oesophagus. The pharynx is absent. The oesophagus on reaching the anterior margin of the ventral sucker bifurcates into two. These two branches reunite in the middle portion of the body to be continued as a single sinuous tube terminating blindly. The oesophagus remains, surrounded by an 'hour-glass shaped' digestive gland.

Excretory system. Excretory system consists of *Protonephridium* and is formed by a posterior *bladder*, lateral *collecting tubules* with anterior and posterior branches and terminal *flame bulbs*.

Nervous system. The *brain* is bilobed and located in the dorsal side just above the middle of the oesophagus. Paired posterior *nerve trunks* are given out from the brain.

Reproductive system

Male reproductive organs. The male reproductive system consists of 4 or 5 *testes*. The testes are located close behind the ventral sucker and are tightly clustered. *Vasa efferentia* from all the testes enter into a short *vas deferens*. The vas deferens at its posterior end has become enlarged to form the *seminal vesicle* which opens directly to the ventral surface immediately behind the ventral sucker.

Female reproductive organs. The female reproductive system consists of a single and elongated *ovary* located in front of the rejoined gut caeca. The oviduct is narrow and it proceeds forward to open into the *ootype*. The ootype opens to the outside on the ventral surface just behind the ventral sucker. The posterior half of the body is filled with alternately lobed *vitelline glands* which pour

their contents into the common *vitelline duct* which opens into the oviduct.

Life History. The schistosomes remain permanently wedded and *monogamous,* the uncoupled females remain as spinsters. At egg laying time the female leaves the male and moves into smaller veins of the bladder and intestine and lays eggs singly. It has been estimated that a female *S. japonicum* lays about 1200 eggs per day. Fig. 13.12 shows the life history of *S. haematobium.*

Egg. The egg is oval in shape. The average size is 120–170 μm by 40–70 μm. It is provided with terminal spine. The eggs retain their position by these spines. The eggs presumably being aided by the histolytic secretions of the contained embryo work their way out of the vessel into the lumen of the bladder and intestine whence they escape with urine or faeces.

Miracidium. Dilution of the faeces or urine causes the egg to hatch into *Miracidium* larva within a few minutes to several hours. In undiluted faeces or urine the egg does not hatch. The body of the miracidium is covered over with cilia. The miracidium possesses two pairs of flame cells. It has a short gut and anterior and lateral penetration glands.

The sex of the future adult worm remains already determined in the miracidium. As the miracidium lives for 24 hours or less, it tries to find out a suitable snail host (intermediate host—*Balinus*). When the miracidia come close to a suitable host they become excited and dash for burrowing into the tentacle or other parts.

Sporocyst. During penetration the ciliated outer covering of the miracidium is shed. The miracidium elongates and becomes transformed into *sporocyst.* The sporocysts are tubular in appearance and make their way through the viscera to the digestive gland. The sporocysts produce within their brood cavities a *second generation of sporocysts.* The daughter sporocysts burst free from the mother sporocyst. From the germ cell masses of the posterior end of these sporocysts *Cercaria* develop.

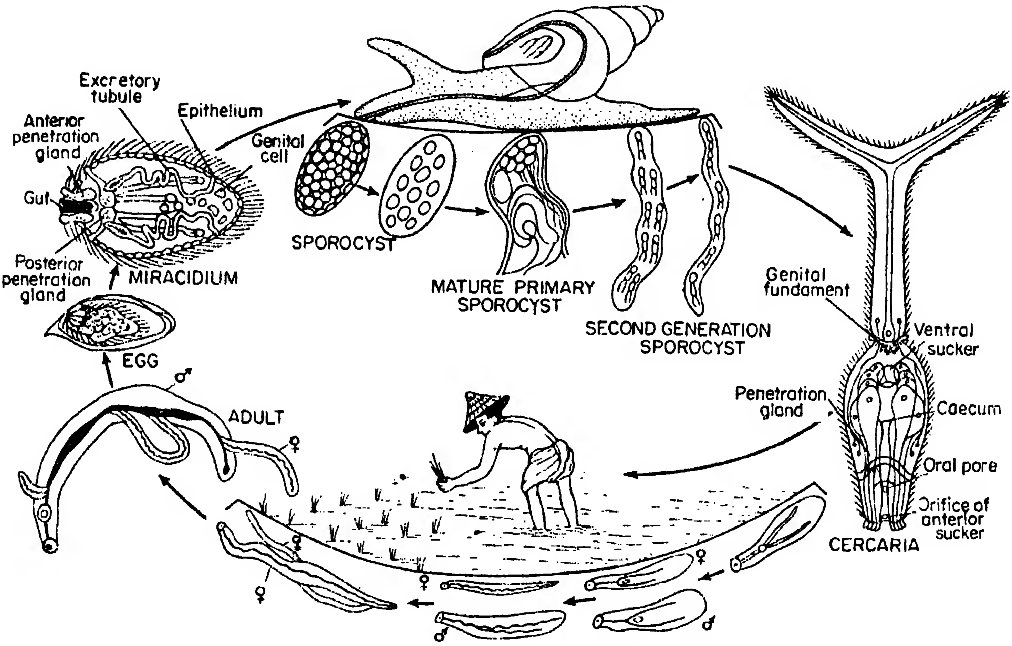


Fig. 13.12. Showing the life history of *Schistosoma haematobium.*

Cercaria. Mature cercariae come out from a birth pore near the anterior end of the sporocyst. The sporocyst continues to produce them for several months. The length of the cercaria is about 200 μm. It is provided with a *forked tail* about 75 μm long. The body of the cercaria bears backwardly pointed spines. The ventral sucker is well developed. Digestive system remains in the rudimentary stage. A 'head organ' occupies the anterior one third of the body. It is provided with two sets of penetration

glands. The penetration glands are unicellular with large nucleus. They escape from the snail into water in 'puffs', a number at a time.

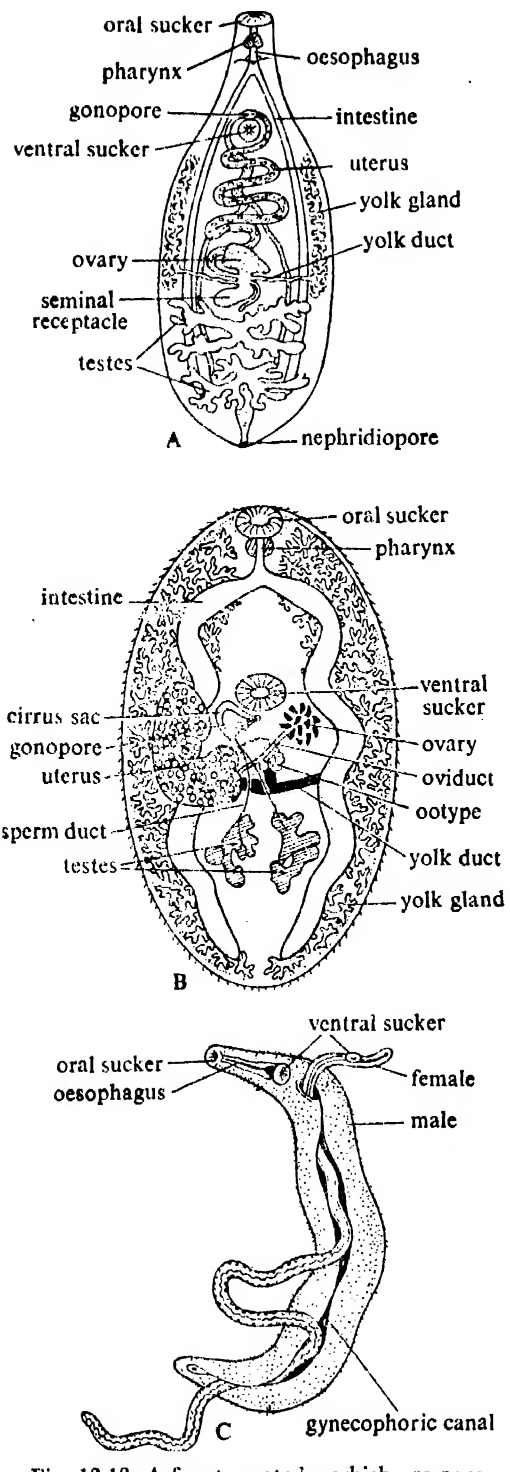


Fig. 13.13. A few trematodes which are parasites in man (after various sources). A. *Clonorchis sinensis*. B. *Paragonimus*. C. *Schistosoma haematobium*.

The forked tailed Cercaria or *Fercocercus Cercaria* swims and rests alternately in water for two or three days. If they fail to reach a final host by this time they die. If successful they either burrow through the skin or are ingested by human beings. While burrowing they employ the histolytic or hyluronidase bearing secretions of the penetration glands. If ingested the cercariae attach themselves to the mucous membrane of the mouth and throat and bore in leaving their tails. Eventually they find their way into the blood stream and are carried to lungs *via* heart. From there they are carried to the liver and then migrate to mesenteric veins.

OTHER TREMATODES

More than 3,000 species of digenetic flukes live as parasites on hosts ranging from fish to mammals. Important flukes which infect mankind are:

FASCIOLOPSIS BUSKI. Intestinal flukes, most prevalent in India and China. Larval stages occur in snail. Cercaria encysted on the leaves of water nuts. When these raw water nuts are consumed by human beings in the Orient the parasites enter the gut.

CLONORCHIS SINENSIS. Reside in the bile duct of man, most prevalent in Japan, China and Vietnam. Primary larval stages occur in snails, secondary in the muscles of fish. Infection results from the consumption of raw or ill-cooked fishes (Fig. 13.13A).

PARAGONIMUS WESTERMANI. Reside in lungs; wide distribution —Japan, China, Philippine, India, Africa and New Guinea. Eggs come out through the sputum of host. Larval stages in snails and then on crabs or cray fishes. Enter into the human body with uncooked crustaceans (Fis. 13.13B).

Example of the Phylum Platyhelminthes—*TAPE WORM*

Habit and Habitat. It is scientifically known as *Taenia solium*. The name tape worm is due to its elongated tape-like appearance. It may attain a length of several metres. It belongs to the class Cestoda. Sexual forms of Taenia occur as endoparasites in the intestine of man. Asexual forms are encountered in

the muscles of pig or in exceptional cases in the muscle of man. Man is its *primary host* and pig is its *secondary host.* Distribution of Taenia is world-wide and is most common in European countries. Nowadays *Taenia solium* occurs rarely in man. *Taenia saginata* is more common, because three parts—a base or guard, a conical blade at the tip and a handle projected from the middle. The hooks are arranged in two rows. Such hooks are absent in *Taenia saginata.* When the contractile rostellum is withdrawn the hooks become anteriorly directed and get fixed into the host tissue.

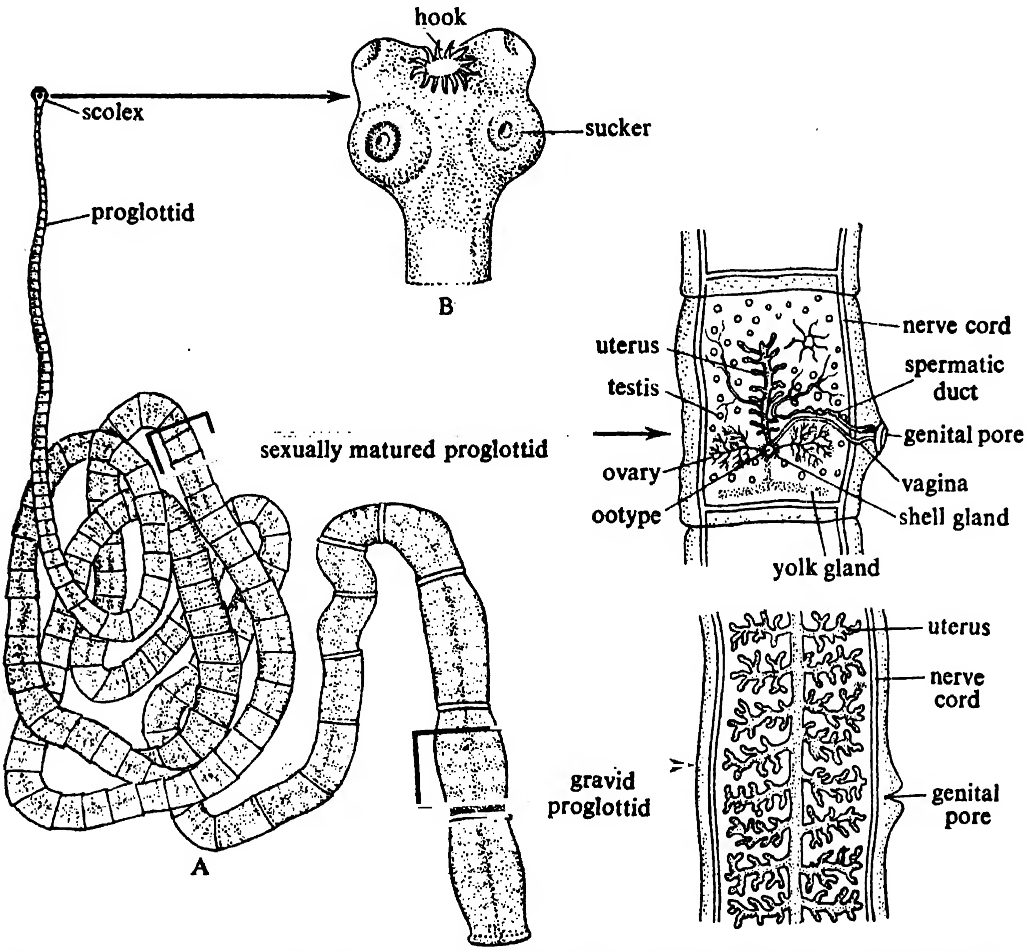


Fig. 13.14. *Taenia solium*—entire specimen and enlarged view of different parts (after various sources).

it uses cattle as the secondary or intermediate host.

Structure. A fully-developed Taenia may attain a length of 3–5 metres. Antero-posterior ends are clearly distinguishable but it is difficult to differentiate the dorsal from the ventral surface. The body is ribbon-like (Fig. 13.14) and consists of a distinct *head* or *scolex* at the anterior region. The tip of the head bears a conical elevation—the *rostellum* which can be retracted or extended. The rostellum bears 28 to 33 hooks. The hooks are of two types—larger and smaller and they alternate with each other. Each hook (Fig. 13.15) has

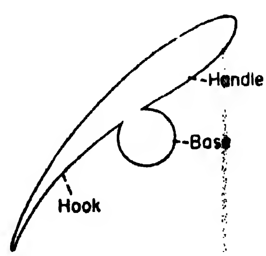


Fig. 13.15. Enlarged view of a hook.

The head bears in the middle four cup-like *suckers* or *Acetabulum.* Rostellum and suckers act as organs of attachment to

the intestine of the host. Behind the head there is a narrow and small tubular region —the *neck* or the zone of proliferation. The rest of the body or tape is called *strobila.* The strobila is segmented in appearance, though this segmentation is not similar to the true segmentations of annelids. The chain-like strobila is made up of about 850 *segments* or sexual units called *proglottids.* The proglottids progressively increase in size and mature towards the posterior extremity. The youngest or newly formed proglottid occupies a position just beneath the neck while the oldest one is at the posterior end. The number of proglottids varies from 800–850 in a full-grown worm.

Structure of a proglottid. A proglottid from the middle region of the strobila offers a rectangular outline (Fig. 13.16). The surface is lined by *cuticle* (recently renamed as *epidermis*). It is thick and perforated at intervals by fine canals, at the bottom of which either gland cells or nerve endings are situated. It is followed by longitudinal and circular layers of muscles. The circular muscles divide the parenchyma cells into an outer cortex and inner medullary region. Towards each lateral margin is found the *longitudinal nerve* and just median to them lies the *longitudinal* pair of *excretory* vessels. A *transverse excretory* canal is situated at a posterior position of the proglottid. The anterio-lateral borders of the medulla are housed with testes and posterior lateral borders are with ovary. The male and female genital ducts open to a chamber called the *genital atrium* which is situated in the middle of one of the lateral margins. The atrium opens to the exterior through an aperture called *genital pore.*

Body wall. The body is covered by a thick *epidermis.* The epidermis is many-layered and perforated. It is impregnated with calcium carbonate. The epidermis remains sunk in the parenchyma. *Longitudinal muscles* run under the epidermis. The *parenchyma* is divided into an outer cortical zone and inner medullary zone by the *circular muscles.* Nervous, reproductive and excretory organs are situated within the medullary zone.

For a long time it was regarded that the body of tapeworm is covered by thick cuticle. But recently electron microscopic studies have revealed that the outer layer of the body of all cestodes contains mitochondria and remains continuous with processes emerging from the cytoplasm of some underlying cells. There is a recent trend to replace the term 'cuticle' by epidermis or tegument. The ontogenetic development of the epidermis is not exactly known. The epidermis bears microvilli which increase the absorptive area of the tapeworms where gut is absent. Beneath the epidermis lies the prominent basement membrane.

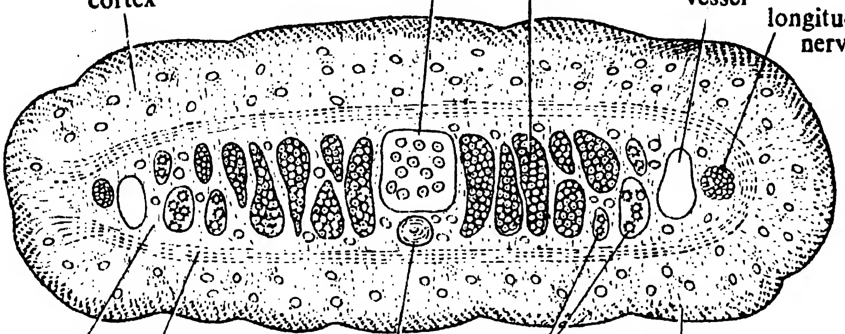


Fig. 13.16. Transverse section of *Taenia solium* passing through a mature proglottid (after Parker & Haswell).

Digestive system. It is completely absent. This absence is due to the parasitic life of the tapeworm. It absorbs nutrient from the intestinal contents of the host.

Excretory system. There are two pairs of *main longitudinal trunks.* Each pair runs along with the lateral margins

of the strobila. The paired state of the longitudinal trunks is well recognised at the anterior part of the strobila and in the posterior part one from each of the pairs becomes lost. The two pairs of the longitudinal trunks are connected with each other in the head region by a ring-like *vessel*. Similar connections by straight *transverse vessels* are seen in the posterior regions of each proglottid. In the last and penultimate proglottid the longitudinal trunks open into a pulsatile *caudal vesicle* which opens to the outside by a single median aperture. When the last proglottid is cast off at maturity, the longitudinal trunks open to the exterior separately and independently. The main trunks give off branches from which numerous fine canaliculies each terminating in a flame cell arise. The structure of the flame cell is similar to that of Fasciola.

Nervous system. The nervous system consists of a pair of ill-defined ganglia situated in the head or scolex. The ganglia are connected to each other by a broad *transverse commissure* of slender nerve. Each sucker is provided with a pair of nerves arising from the ganglion. Two *longitudinal* nerves of considerable thickness arise, one each from the ganglion and run along the lateral margin up to the last proglottid. Each longitudinal nerve gives a pair of *accessory* nerves.

Reproductive system. Taenia is *hermaphrodite*. Male and female reproductive organs resemble those of the liver fluke. Each proglottid behind the first 200 is equipped with a set of reproductive organs. Male reproductive organs develop first in each proglottid and then female organs make their appearance.

Male reproductive organs. There are numerous rounded *testes* distributed along the length and breadth of the proglottid. Each testis is provided with a fine *efferent duct*. The efferent ducts of neighbouring regions join together and form larger ducts. These larger ducts open into the *vas deferens* or main duct of the testes. The vas deferens is convoluted, transverse in position and extends towards the lateral margin (left or right) of the proglottid. The tip of the vas deferens is narrow and it pierces a narrow protrusible process the *cirrus* and opens at its extremity in the *genital atrium*.

The base of the cirrus is enclosed in a muscular sac—the *cirrus sac*.

Female reproductive organs. There is a pair of bilobed *ovaries* or *germaria* situated in the posterior region of the proglottid. The two lobes are unequal in size and lie one on each side of the median line. The ovaries are made up of numerous branching tubules which converge to form the *oviducts*. The two oviducts meet and form a common median oviduct. A single *vitelline gland* or *yolk gland* consisting of few lobules is situated at the posterior border of the proglottid and opens into the median oviduct through *yolk duct*. Numerous round *shell glands* (also designated as *Mehlis' gland*) are situated round the *yolk duct* and the shell gland ducts open into the oviduct by the side of the yolk duct. The specialised part of the oviduct where shell gland ducts and yolk duct open is called the *ootype*. The ootype passes anteriorly into a median, elongated and blind *uterus*. A fertilizing or spermatic duct arises from the ootype. The anterior part of the spermatic duct becomes dilated to form the *receptaculum seminalis*. From the receptaculum seminalis arises the *vagina* which runs forward and lateral and opens into the *atrium*. In a mature or *gravid* proglottid the uterus becomes distended and branched and occupies the major space inside the proglottid. Consequently other structures become reduced and modified.

Life history. Taenia practices *self-fertilization*, i.e. eggs are fertilized by sperms from the same proglottid or one proglottid may be inseminated by a proglottid situated anterior to it. This is achieved by the bending of the strobila into folds. The possibility of a cross-fertilization is remote since no host will be in a position to house two large tapeworms at a time.

Fertilization occurs inside the ootype and fertilized eggs become surrounded by mass of *yolk cells* secreted by the yolk gland. The fertilized ovum and yolk cells are subsequently enclosed in a thick *egg shell* secreted by the shell glands. Finally the eggs pass to the uterus. The first completed eggs are encountered in the uterus of the proglottid ranging between 400–500.

In the uterus the development of the egg starts (Fig. 13.17). The first cleavage results a large *megamere* and a small *embryonic cell*. Both the megamere and the small embryonic cell divide and the descendants of the megamere ultimately form an

envelope called *embryophore* round the embryonic cells. From the embryonic cells develop the embryo proper. Later on, six hooks develop in the posterior pole of the embryo and it is now called a *hexacanth embryo*. The whole structure containing the embryo, embryophore and egg-shell is called *onchosphere*. Terminal

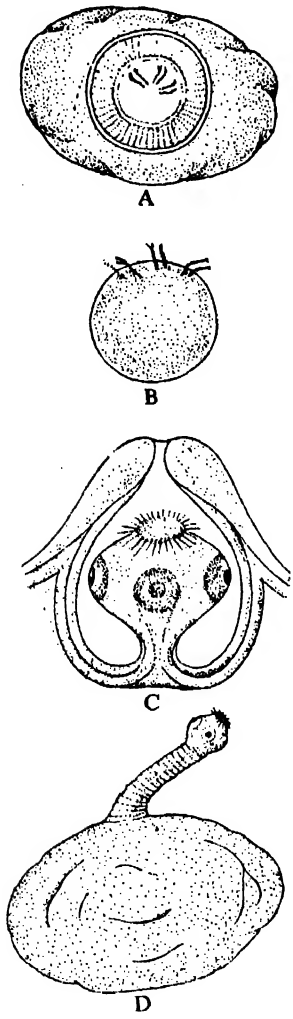


Fig. 13.17. Development of tapeworm (after Guyer & Lane). A. Egg. B. Hexacanth embryo. C. Inverted cyst. D. Cysticercus stage.

proglottids containing onchosphere break off from the strobila (four or five at a time) and pass out of the body of the host along with the faeces. A newly-shed proglottid wriggles for some time but eventually dies and disintegrates. The onchospheres are not affected but further development within them do not occur until they enter the body of the secondary host (pig) through its food. In the stomach of the pig, as the egg-shell and embryophore get digested the *hexacanth embryo* is released. The embryo with the help of its hooks bores into the wall of the gut and reaches the blood stream. Then it reaches the voluntary muscles or tongue or any other muscular tissue *via* heart and becomes encysted.

Inside the cyst the embryo increases in size. A large cavity filled with watery fluid is formed inside the cyst and whole structure assumes a bladder-like appearance. At one point in the bladder an invagination occurs and at the bottom of the invagination a small scolex—the *proscolex* is formed. The embryo at this stage is called *cysticercus* or *bladder-worm*. It does not develop further. Pork meat infected with bladder-worms is spotted in appearance and if such imperfectly cooked meat is eaten, the bladder-worms enter the body of man. The invagination is everted and the scolex attaches itself to the wall of the intestine, develops the neck which buds off proglottids.

Pathogenic effects. Taenia may cause—(*i*) cerebral cysticercosis, (*ii*) may bring about reduction and complete occlusion of the lumen of intestine, (*iii*) anaemia and (*iv*) gastric disturbances leading to regurgitation of gravid proglottids.

Example of the Phylum Platyhelminthes—*ECHINOCOCCUS*

Echinococcus granulosa causes a disease called echinococcosis or hydatid disease. The disease is world-wide in distribution. Human cases are common in Iceland, South Australia, North America, Central and Northern Europe, parts of America, New Zealand.

Habitat. The adult worm lives in the small intestine of dogs and allied animals. The dog is the optimum definitive host. The larval stage is passed in sheep, cattle, pig or man which represent the intermediate hosts of the parasite. These animals, therefore, serve as the common reservoirs of the hydatid diseases.

Structure. This parasite is the smallest tapeworm (in adult stage) of medical importance.

The adult worms measure 5–8 mm in length and are usually with three seg-

ments plus a scolex and a neck (Fig. 13.18). It has a typical taenioid scolex with four deep, well-developed suckers and an anteriorly located retractile rostellum beset with 30–36 hooklets. The scolex contains internal concentration of nervous and excretory systems. Behind the scolex lies the unsegmented proliferous neck region. oospheres) hatch out in the duodenum. The liberated onchospheres bore their ways through the intestinal wall and enter the radicles of the portal vein. Whenever the onchosphere settles, it forms a hydratid cyst. The young larva transforms into a hollow bladder. The cyst is double-walled. The outer layer is laminated while the inner

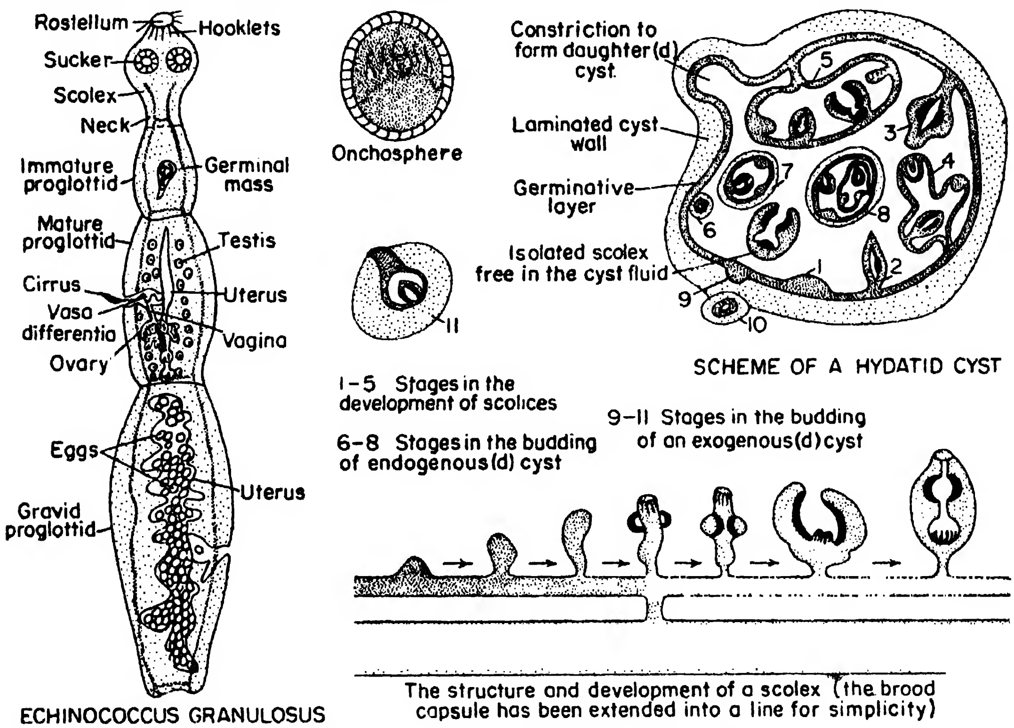


Fig. 13.18. Showing the life history of *Echinococcus granulosa.*

The first proglottid has no definite organisation but the beginning of genital organs is marked by the presence of germinal mass. The second proglottid is mature and contains fully-developed genital organs. The last proglottid is gravid and relatively larger than other two segments. It contains only the uterus filled with eggs.

Eggs. The eggs are ovoid in shape. The egg contains hexacanth embryo with 3 pairs of hooks.

Life cycle. The eggs produced by the adult worms in the intestine of dog or any other suitable primary host pass out along with the faeces and are ingested by the intermediate host with contaminated food or drink. The eggs, when swallowed, pass down the oesophagus into the stomach. Inside the stomach the shell wall is digested and the active hexacanth embryos (onchospheres)

one is germinative. Fig. 13.18 shows the scheme of a hydatid cyst formation. The young larva changes into a hollow bladder around which the host adds an enveloping fibrous cyst wall. With the advent of maturity, the inner surface begins to produce hollow brood capsules. The brood capsule is formed by the proliferation of the cells from the germinative layer about eight months after the beginning of the cyst formation. It starts as a small nuclear mass which grows and becomes vacuolated to form a small vesicle. The brood capsules remain attached by slender stalks and often set free into the fluid-filled cavity of the mother cyst. As the cyst grows larger, more brood capsules develop. The older brood capsules begin to differentiate a number of scolices on their inner walls. The mother cysts may, as a result of intracystic pressure, develop hernia-like buds which detach themselves and con-

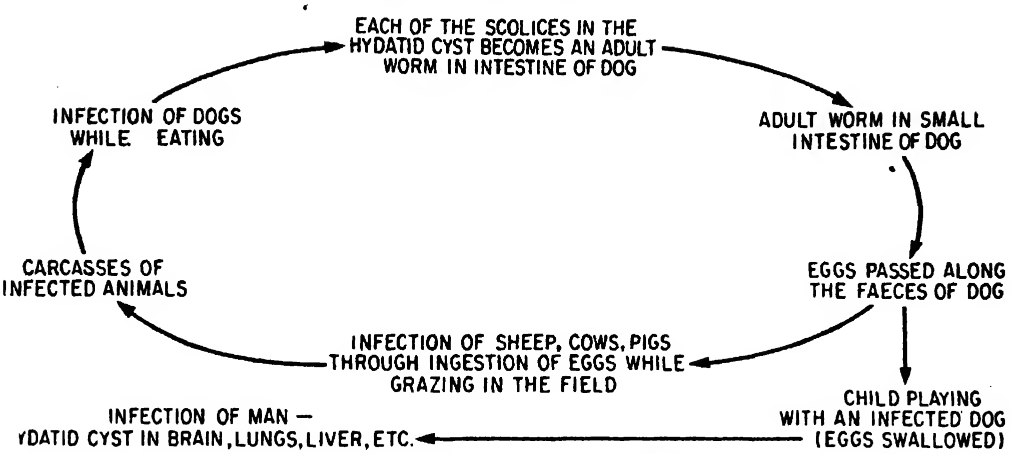


Fig. 13.19. Schematic representation of the life cycle of *Echinococcus granulosa*.

tinue their development independently as daughter cyst.

Formation of daughter cysts. The mother hydatid cyst develops daughter cysts. The daughter cysts are generally endogenous in origin while the exogenous daughter cysts occur rarely. The endogenous cysts arise from the germinative layer. The daughter cyst is almost identical to the mother cyst. Each scolex developed from the daughter cyst has the property of becoming a new hydatid in an intermediate host.

Transmission. The end product of the hydatid cyst is the production of the scolices and each scolex has the power to develop into the strobilate worm, when ingested by any primary host (especially dogs). As a single hydatid may contain thousands of brood capsules and each brood capsule may give origin to a large number of scolices, the number of strobilate worms resulting from such ingestion of a single hydated cyst become numerous. Attainment of strobilate stage in the intestine of dog requires 3–10 weeks after ingestion. Man becomes infected in a variety of ways—*viz.*, by swallowing food or drinks contaminated with infested canine faeces or by handling the infested dogs. The life cycle of *Echinococcus granulosa* is schematically represented in Fig. 13.19.

OTHER CESTODES

Over 1,500 species of cestodes are known to live as parasites on different animals ranging from fish to mammals (Fig. 13.20). Primary host harbours the adult stages while embryonic stages occur in secondary hosts. Infection is caused when the secondary hosts are eaten by the primary hosts.

HYMENOLEPIS NANA. Intermediate host is usually absent. Adults occur

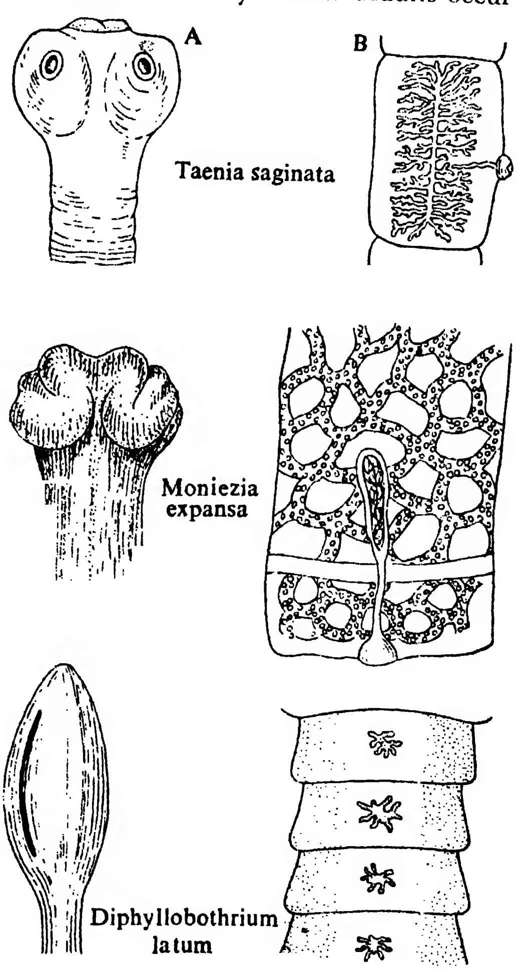


Fig. 13.20. Showing the scolices (A) and proglottids (B) of three cestodes (after various sources).

in the lumen of the intestine of man, and the larvae live in the intestinal villi. Proglottids numbering about 200. Popularly known as dwarf tapeworm. It measures about 10–45 mm.

TAENIA SAGINATA. Adult infects man, larvae live in cattle, proglottids are 2,000 in number (Fig. 13.20). T. *saginata* is a more common cestode parasite in man, because it uses cattle as its intermediate host. It resembles T. *sobium* but the rostellum is without hooks and the mode of branching of gravid uterus is different.

TAENIA PISIFORMIS. Adults occur in the dog or cat, larvae stay in the liver and mesenteries of rabbit.

MONIEZIA EXPANSA. Adults reside in sheep, larvae remain in mites. It extends up to six metres in length (Fig. 13.20).

DIPHYLLOBOTHRIUM LATUM

Diphyllobothrium latum (also known as *Dibothriocephalus latum*), commonly called the fish-tapeworm, is the largest known cestode measuring about 18 metres in length. The number of proglottids varies from 3000–4000. It has an extremely elongated slender neck. The scolex has two slit-like bothria (Fig. 13.20) but hooks are absent. The secondary hosts of this form are crustaceans (first host) and various freshwater fishes are the second host. Man or other carnivorous animals are its primary hosts.

ADAPTIVE FEATURES IN CESTODES. (*a*) The covering of the cestodes is not digestable by the host's digestive juices and it is permeable to water, (*b*) the osmotic pressure inside the body of the parasite is lower than the surrounding medium, (*c*) pH tolerance is high, (*d*) glycogen and lipid contents in the body tissues of cestodes are high and protein content is less, (*e*) in the absence of oxygen it can respire anaerobically, (*f*) the bladder of cysticercus is digested by the digestive juice but the scolex escapes digestion, (*g*) the eversion of scolex is accelerated by the bile of the host.

TABLE 1—PLATYHELMINTHES

COMPARATIVE ACCOUNT OF FASCIOLA HEPATICA AND TAENIA SOLIUM

	Fasciola hepatica	*Taenia solium*
1. Status	Class–Trematoda (or class Digenea)	Class–Cestoda.
2. Distribution	Asia, America, Europe, Africa	World-wide.
3. Habitat	Adults live in the bile duct of the liver of sheep, cows, pigs, etc. and occasionally found in man. Larval forms occur in snail.	Adults live in the alimentary canal of man, 'cyst' forms occur in pig.
4. Structure	Body flat and leaf-like, size varies from 1·0 to 2·5 cm in length, width is about 1 cm. Anterior end is conically projected to form the 'head lobe'. There are two suckers. Anterior sucker is situated at the apex of the head lobe—the ventral sucker is situated ventrally and little below the head lobe. Single median genital pore is situated ventrally and in between the two suckers. Single excretory aperture lies at the extreme posterior end of the body. A thick cuticle bears spine-like thickenings.	Body flat and ribbon-like, consisting of a knob-like head or 'scolex' and a great number of similar parts called proglottids arranged in a single row. A short neck remains in between the scolex and the proglottids. Proglottids gradually increase in size from anterior to posterior. An individual may attain a length of 3 metres and number of proglottids may be about one thousand. The scolex bears at its tip a rostellum with double rows of curved chitinous hooks and four suckers.

TABLE 1—PLATYHELMINTHES (contd.)

.	*Fasciola hepatica*	*Taenia solium*
5. Alimentary system	Mouth lies in the middle of anterior sucker and is followed by a suctorial pharynx. Oesophagus is short and soon bifurcates to form the intestine. Many caeca originate from the main branches of the intestine and traverse almost every region of the body. There is no anus.	There is no alimentary canal, absorbtion occurs through general body wall predominently by diffusion.
6. Excretory system	The main excretory canal opens to the exterior through an aperture situated at the posterior end of the body. The duct receives many tubules each of which ends in a flame bulb.	Each proglottid houses many flame-bulbs arranged superficially and having drainage tubules. These tubules carry the excretory products to two longitudinal canals placed laterally. These lateral canals are joined by transverse canals. The ends of the lateral canals act as excretory pores.
7. Nervous system	Consists of prominent masses called cerebral ganglia joined together by a nerve ring around the oesophagus. From the ganglia nerves are given off to the head lobe and to the posterior part of the body. One pair of these posterior nerves is larger and more stout than the others.	The scolex bears a transverse band of nervous material. This ganglionated mass gives out slender branches to the suckers and to the posterior parts of the body. Two stouter nerves run laterally along the long axis of the body.
8. Reproductive system	Individuals are hermaphrodite. Sex organs are well-developed. The male organs consist of a pair of much branched testes, two vasa deferentia, a pear-shaped seminal vesicle, a convoluted ejaculatory duct and a muscular penis. Female organs consist of single and branched ovary, a convoluted oviduct, shell gland, a uterus, which leads to the genital pore. Accessory glands—yolk or vitelline glands open through ducts in the shell gland. A canal called Laurer's canal running between the point of fusion of vitelline duct and oviduct at one end and the dorsal surface at the other end. Cross-fertilization is the rule.	Individuals are hermaphrodite. Sex organs are repeated in each proglottid. A mature proglottid is almost filled with sex-organs. Male organs consist of numerous testes, efferent ducts, vas deferens and a protrusible penis lying in the genital atrium located on one of the lateral borders. Female organs consist of ovary which is bilobed and situated at the hinder end—a short oviduct, and vagina which opens into the genital atrium. Uterus is much branched and originates from the base of the oviduct. A median and compact vitelline gland and a shell gland surround the base of the uterus and oviduct. Laurer's canal is absent. Self-fertilization takes place.

TABLE 1—PLATYHELMINTHES (contd.)

	Fasciola hepatica	*Taenia solium*
9. Life history	(*a*) Fertilized eggs develop into ciliated Miracidium larva and it forces its way into the snail's body. (*b*) Miracidium changes to Sporocyst within which Rediae are developed. (*c*) Rediae produce daughter Rediae. (*d*) Rediae (daughter) give rise to Cercariae which leave the snail's body and on reaching its primary host (sheep) develop into adult flukes.	(*a*) Fertilized eggs develop into six-hooked Hexacanth larva while still within the proglottid. (*b*) On reaching the pig they force their way into the voluntary muscle and form cysts. (*c*) The wall of the cyst gives rise to a head and is known as Cysticercus at this stage. (*d*) On reaching man the Cysticercus gives off series of proglottid and becomes mature.

TABLE 2—PLATYHELMINTHES

COMPARISON OF DEVELOPMENTAL PROCESSES IN TYPICAL CESTODES AND TAENOIDS

	Typical Cestodes	*Taenoids*
1. Egg (*a*) Capsule (*b*) Cells	(*a*) The capsule is thick and operculated or non-operculated. (*b*) A single egg cell and a number of yolk cells.	(*a*) The capsule is thin and rather delicate—usually non-operculated. (*b*) Typically a single egg cell and a single yolk cell.
2. Segmentation	2. Total and equal—holoblastic.	2. Total and unequal giving rise to three types of identifiable cells—the macro, micro and mesomeres
3. Outer embryonic membrane	3. Some blastomeric cells situated at a particular pole spread to form it.	3. The macromeres form a syncytium to form the outer embryonic membrane.
4. Inner embryonic membrane	4. (*a*) Some blastomeric cells by the process of epiboly, forms the inner embryonic membrane. (*b*) It is not cuticularised but gives rise to cilia.	4. (*a*) The mesomeres form the inner embryonic membrane. (*b*) It is cuticularised and cilia are never formed out of it.
5. Fate of different membranes (*a*) Capsule (*b*) Outer membrane	5. (*a*) usually shed. (*b*) usually shed.	5. (*a*) usually shed. (*b*) usually shed but may be drawn out into filament on each side.

TABLE 2—PLATYHELMINTHES (contd.)

	Typical Cestodes	*Taenoids*
6. Miracidium	6. Miracidium stage is present.	6. Miracidium stage is absent.
7. Development in the intermediate host	7. Miracidium develops into a larva with scolex and cystic appendages are of different shapes and sizes.	7. The oncosphere embedded in the hard inner membrane when eaten up by the appropriate host develops directly into the Cysticercus stage.

CLASSIFICATION

The classification of platyhelminthes is complicated and has not yet been properly finalised. It was Linnaeus (1735) who first included them with other worms in the phylum *Vermes*. Lamarck (1816) separated them from other worms and Cuvier included them within Zoophyta or Radiata. The name platyhelminthes of the phylum was first coined by Minot (1876).

CLASSIFICATION IN OUTLINE

Phylum Platyhelminthes is usually divided into three classes—*Turbellaria*, *Trematoda* and *Cestoda*.

PHYLUM PLATYHELMINTHES

Class **Turbellaria**

- Order *Acoela*, e.g. *Convoluta*, *Ectocotyla*.
- Order *Rhabdocoela*, e.g. *Temnocephala*, *Stenostomum*.
- Order *Alloeocoela*, e.g. *Prorhynchus*, *Plagiostomum*.
- Order *Tricladida*, e.g. *Euplanaria*, *Procotyla*.
- Order *Polycladida*, e.g. *Notoplana*, *Planocera*.

Class **Trematoda**

- Order *Monogenea*, e.g. *Polystoma*, *Sphyranura*.
- Order *Aspidobothria*, e.g. *Aspidogaster*, *Stichocotyle*.
- Order *Digenea*, e.g. *Schistosoma*, *Clonorchis*.

Class **Cestoda**

Subclass CESTODARIA

- Order *Amphilinidea*, e.g. *Amphilina*.
- Order *Gyrocotylidea*, e.g. *Gyrocotyle*.

Subclass EUCESTODA

- Order *Tetraphyllidea*, e.g. *Phyllobothrium*.
- Order *Lecanicephaloidea*, e.g. *Polypocephalus*.
- Order *Proteocephaloidea*, e.g. *Proteocephalus*.
- Order *Diphyllidea*, e.g. *Echinobothrium*.
- Order *Trypanorhyncha*, e.g. *Haplobothrium*.
- Order *Pseudophyllidea*, e.g. *Dibothriocephalus*.
- Order *Nippotaeniidea*, e.g. *Nippotaenia*.
- Order *Taenioidea*. e.g. *Taenia*, *Echinococcus*, *Hymenolepsis*.
- Order *Aporidea*, e.g. *Gastrotaenia*.

CLASSIFICATION WITH CHARACTERS

Class **Turbellaria.** Free-living; body is undivided; cilia are scattered on epidermis; rhabdites are rod-like; mucous glands are present; pigmented and some are brilliantly coloured; mouth is ventral and intestine is present; suckers are absent; development is direct, asexual reproduction occurs in many. It includes 5 orders.

Order *Acoela*. Marine; with mouth, pharynx and intestine; protonephridia and gonads are absent, e.g. *Convoluta*, *Ectocotyla* (commensal on hermit crab).

Order *Rhabdocoela*. Marine or freshwater; colourless; digestive tract is straight; protonephridia are either 1 or 2; commensal or parasite; some are with tentacles, e.g. *Temnocephala*, *Stenostomum*.

Order *Alloeocoela.* Mostly marine; cylindrical; intestine is straight or with branches, e.g. *Prorhynchus, Plagiostomum.*

Order *Tricladida.* All live in fresh-water; mouth is mid-dorsal and with proboscis; digestive tube is with 3 branches; eyespots are present, e.g. *Euplanaria, Procotyla.*

Order *Polycladida.* Marine; with many eyes; oval; intestine is with irregular branches, e.g. *Notoplana, Planocera.*

Class **Trematoda.** All are parasites; rhabdites or cilia are absent in epidermis; body is covered by cuticle; presence of one or more suckers for attachment; mouth is anterior; digestive tract is complete and with two branches. No asexual reproduction takes place. In most cases the testes are two but always one ovary is present; 3 orders.

Order *Monogenea.* Sucker is weak or absent; posterior end bears adhesive disc and hooks; paired excretory pores are located anterodorsally; ectoparasite on cold-blooded vertebrates; life cycle is simple and having no alternation of host; larva is ciliated, e.g. *Polystoma, Sphyranura.*

Order *Aspidobothria.* Oral sucker or anterior adhesive disc is absent. Ventral surface has a big sucker or rows of suckers. Single posterior protonephridium is present. Endoparasite with simple life cycle, e.g. *Aspidogaster, Stichocotyle.*

Order *Digenea.* Mostly with two suckers, no hooks, single excretory pore is situated posteriorly; uterus is long and tubular; life cycle is complicated with one or more intermediate hosts; chiefly endoparasite, e.g. *Fasciola, Schistosoma, Clonorchis.*

Class **Cestoda.** Endoparasites; body is divided into segments; mouth, digestive tract and sense organs are absent; organs of attachment in the form of hooks and suckers are present; each segment excepting the head and neck is provided with one or two sets of complete sex organs; hermaphrodite, embryo hooked, life cycle is complicated. Includes two subclasses.

Subclass CESTODARIA. Body is undivided; no scolex; one set of reproductive structure is present; larva is with 10 hooks.

Order *Amphilinidea.* Proboscis is protrusible; frontal glands are placed at anterior end; male and female genital pores posterior in position; uterus is extensive in length and traverses the body, e.g. *Amphilina* in the fish, sturgeon.

Order *Gyrocotylidea.* Anterior end is with eversible proboscis; posterior end is with adhesive disc; uterus runs direct to the pores, e.g. *Gyrocotyle* in chimaeroid fish.

Subclass. EUCESTODA. Long; ribbon-like; segmented; scolex bears adhesive organs; may be with more than one set of reproductive organs in a proglottid; larva bears six hooks.

Order *Lecanicephaloidea.* Scolex is differentiated into two parts, upper with disc or branches and lower with suckers, e.g. *Polypocephalus* (lives as parasite in elasmobranch fishes).

Order *Tetraphyllidea.* Scolex bears 4 longitudinal slits called bothridia; often with hooks, e.g. *Phyllobothrium* (lives as parasites elasmobranch fishes).

Order *Proteocephaloidea.* Scolex with 4 lateral and one apical suckers, e.g. *Proteocephalus* (lives as parasite in the intestine of fish, amphibia and reptile).

Order *Diphyllidea.* Scolex is large, lobed, neck with 8 rows of hooks. One genus, e.g. *Echinobothrium* (lives as parasite in elasmobranch fishes).

Order *Trypanorhyncha.* Scolex with four lobes or bothridia and spiny protrusible proboscis, e.g. *Haplobothrium.*

Order *Pseudophyllidea.* Scolex indistinct; 2–6 shallow bothridia; adhesive glands absent, e.g. *Dibothriocephalus.*

Order *Nippotaeniidea.* Small; no scolex; one apical sucker is present, e.g. *Nippotaenia.*

Order *Taenoidea.* Scolex with 4 suckers and usually with hooks at tip; sex aperture is lateral in position, e.g. *Taenia, Echinococcus, Hymenolepsis.*

Order *Aporidea.* Scolex with 4 suckers and rostellum; no yolk gland, sex ducts or pores, e.g. *Gastrotaenia* (lives as parasite in Swan).

Recently J. Llewllyn (as cited in the Text Book of Zoology—Parker and Haswell Vol. I, 7th Edition, 1972) presented a scheme of classification of Phylum Platyhelminthes. The outline of the scheme is given below to give a guide line.

Phylum Platyhelminthes
↓
Class

- 1. Turbellaria
  - ↓ (Sub-class)
    - *Archoophora* (Orders)
      - → *Acoela*, e.g. *Convoluta*
      - → *Polycladida*, e.g. *Thysanozoon*
    - *Neoophora* (Orders)
      - → *Rhabdocoela*, e.g. *Actinodactylella*
      - → *Temnocephala*, e.g. *Temnocephala*
      - → *Tricladida*, e.g. *Bipalium*.
- 2. Digenea, e.g. *Fasciola*
- 2. Aspidogastrea, e.g. *Aspidogaster conchicola*
- Monogenea
  - ↓ (Orders)
    - → *Monopisthocotylea*, e.g. *Eutobdella*
    - → *Polyopisthocotylea*, e.g. *Polystoma*
    - → *Gyrocotylidea*, e.g. *Gyrocotyle*
- Cestoda
  - ↓ (Orders)
    - → *Caryophyllidea*, e.g. *Caryophyllaeus*
    - → *Spathebothridea*, e.g. *Cyathocephalus*
    - → *Diphyllobothridea*, e.g. *Diphyllobothrium*
    - → *Bothriocephalidea*, e.g. *Eubothrium*
    - → *Tetraphyllidea*, e.g. *Acanthobothrium*
    - → *Trypanorhyncha* or *Tetrarhynchidea*, e.g. *Tetrarhynchus*.
    - → *Proteocephalidea*, e.g. *Ophiotaenia*
    - → *Cyclophyllidea*, e.g. *Taenia*

GENERAL NOTES ON PLATYHELMINTHES

HISTORY

Parasitic flatworms are known to mankind from ancient time. Records of some parasitic tapeworms have been obtained from Egyptian papyrus dating from 1550 B.C. Mention of bladder-worms and tapeworms is common in ancient books of medicine. Linnaeus in his *Systema Naturae* (1735) created a phylum Vermes in which he included all invertebrates except the insects. Appreciation of the peculiar nature and structure of platyhelminthes was made by Minot (1876).

HABIT AND HABITAT

The platyhelminthes are mostly ecto- or endoparasitic and few are free-living. The free-living ones belong to the class Turbellaria and live in fresh water, ponds, lakes, streams and springs. Some of them are found in shores in tropical and subtropical regions. Trematoda and cestoda are total parasites. In adult stage they parasitise vertebrates and in larval stages they occur as parasites of the invertebrate animals.

STRUCTURE

The members of the phylum are usually elongated in appearance. The Polyclads are broad leaf-like while the tapeworms are flat and ribbon-like. The contour of the body is simple in general but some trematodes offer bizzare contour. The bodies of the tapeworms are made up of a number of squarish or rectangular segments called *proglottids*. The anterior proglottid is smallest and the posteriormost proglottid is largest. That means, the size of the proglottid increases in the antero-posterior direction. The presence of proglottids imparts in the tapeworms a segmented condition. Some sort of *pseudo-metamerism* is encountered in *Procerodes lobata* in which some of the internal organs are repeated.

Anterior and posterior ends as well as dorsal and ventral surfaces are easily recognisable. Often the anterior end is marked off from the rest of the body by the presence of a 'head' followed by a constricted 'neck'. In some forms definite head is lacking but the anterior end can be detected by the sense organs or by its being directed forward during locomotion. Ventral surface bears mouth and genital apertures, when present.

The sizes of platyhelminthes range from microscopic to extreme elongated forms as long as 10–15 metres in length (Tapeworms). Most of the members are of small to moderate dimensions. The platyhelminthes in general are colourless or white in colour. Free-living forms are white, brown, grey or black in colour. Some polyclads and land planarians are with bright colours arranged in patterns.

ORGANS OF ADHESION OR SUCKERS

The platyhelminthes possess a variety of organs of adhesion and attachment. Acetabulum or sucking organ in the form of 'sucker' is very common in adult flat worms. In flukes, there are two suckers on the ventral side of the body. One of these suckers is located in the anterior side of the body and its position is more or less fixed. While the other one called the posterior sucker is not constant in position. In *Paramphistomum* the sucker is posteriormost in position, in *Echinostoma* and *Fasciola* the position is shifted more anteriorly.

In tapeworms the adhesive organs are present in the form of grooves or cups and are situated at the cephalic end. Often hooks are present near these grooves or in the eversible buccal chamber to aid in anchorage. Suckers also occur in some free-living Planaria.

BODY WALL

Platyhelminthes lacks exo- or endoskeleton and as such the body is soft. The epidermis is single-layered and in some cases it is syncytial. The epidermis may be ciliated in whole or in part. The subepidermal layer consists of musculature of circular, longitudinal and oblique fibres. The muscle fibres are smooth. All the spaces between the organs are filled in with packing cells called parenchyma.

The hard parts in Platyhelminthes are the hooks and spines. Many earlier workers regarded that the body of monogeneans, digeneans and cestodes is covered by 'cuticle'. Non-ciliation in these forms gives the false impression of cuticle under light microscopy. But electron micros-

-copic studies have revealed the outer layer of the body to be epidermis. The cells in this layer contain microchondria and remain continuous with the underlying cells.

DIGESTIVE SYSTEM

Digestive system is absent in the turbellarian order Acoela and in the cestodes. In Turbellaria and Trematoda alimentary system is represented by mouth, pharynx and intestine which ends blindly and as such the entire disposition of digestive organs closely resembles that of anthozoans and ctenophores. The mouth in primitive condition is situated at about the middle of the ventral line but in many flat worms the position is shifted anteriorly along the mid-ventral line. Mouth is absent in endoparasitic rhabdocoels. The pharynx is stomodaeal in nature and is a strong muscular tube. It shows variation in the phylum. The intestine shows wide variation in form. It may be a simple sac or may have complicated branchings and sub-branchings. Anal openings are rarely present.

EXCRETORY SYSTEM

Excretory system of platyhelminthes consists mainly of longitudinal water vessels and numerous flames cells or flame bulbs or paranephridia. The arrangement of water vessels inside the body offers wide range of variation. In triclads there are two longitudinal vessels which open to the outside by numerous pores (Fig. 13.21G). The rhabdocoels have two lateral or a single median vessels (Fig. 13.21E). The median vessel opens to the outside by a single pore situated at the posterior end of the body. In forms where two vessels are present the openings are either on the ventral side or in the pharynx. In some forms the two vessels unite at the posterior region and open to the outside by a single median aperture. The main nephridial canal is extensively branched and there are accessory excretory pores besides the nephridiopore (Fig. 13.21F). In monogenic trematodes there are two longitudinal excretory ducts and the two ducts open separately on the dorsal surface. The ducts dilate to form excretory sacs at their terminal ends.

In other trematodes the excretory ducts are connected posteriorly to one another by a transverse duct and open to the outside by a single median aperture. The transverse duct dilates and in some cases forms an excretory vesicle. The two longitudinal ducts may unite with each other in the posterior region and may have a single opening.

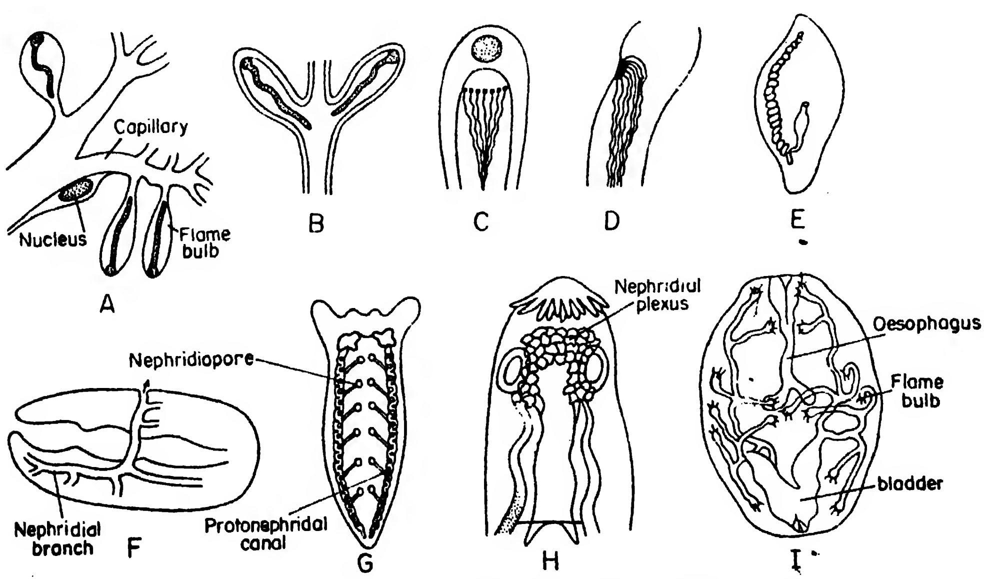


Fig. 13.21. Showing the excretory organs in different Platyhelminthes. A. A part of nephridia showing flame bulb derived from a single cell. B. Flame bulb showing the tip of flame. C. Typical flame cell. D. A typical flame cell. Nephridium of *Rhabdocoeles* (E), *Alloeocoeles* (F), Triclad (G). H. Nephridial plexus of *Taenia*. I. Excretory organs of *Microphallus*.

In cestodes there are four longitudinal excretory vessels. The excretory vessels are connected by a transverse vessel situated in the scolex to form nephridial plexus (Fig. 13.21H) and open in a contractile excretory vesicle situated in the last proglottid.

RESPIRATORY AND CIRCULATORY SYSTEMS

These two systems are totally absent in the phylum. In some trematodes the presence of a system of tubes called lymphatic system has been described. The tubes are considered to be of uncertain functions.

NERVOUS SYSTEM

The main nervous centre or *brain* is located in the head as a pair of cerebral ganglia. Several ganglionated *longitudinal cords* arise from the brain. Of these longitudinal cords a pair becomes most conspicuous and the rest becomes insignificant. Numerous transverse connections occur between the longitudinal cords and the whole nervous system becomes ladder-like in appearance.

Sensory organs as *ocelli* or *eyes* are present in turbellarians and monogenic trematodes. They are numerous in polyclads and two to four in Rhabdocoels and monogenic trematodes. The eyes are present either as pigment cells or in the form of cups containing pigmented and sensory cells. *Chemo-* and *tangoreceptors* are present widely and statocysts occur in Acoela and few other forms.

REPRODUCTIVE SYSTEM

Excepting a few Turbellaria and Trematoda, the platyhelminthes are hermaphrodites. Male and female reproductive organs in each individual are separate and open externally by their own pores or by a common genital aperture. In some cases the gonoducts open into the digestive tract and the sex cells are liberated through the mouth. In some flat worms an extra female pore or vaginal pore which serves during copulation is present. The gonopores are usually ventral in position but are occasionally dorsal. In tapeworms the gonopore is lateral in position.

Male reproductive organs consist of *testes* which in primitive condition are numerous and scattered. The number of testes are reduced to one or two in many and in Acoela definite gonads and ducts are lacking. The *vasa efferentia*, when present, correspond to the number of testes present. In general there is a pair of *vasa deferentia* which unite and open into the complicated copulatory apparatus. The copulatory apparatus consists of an eversible *cirrus* or a protrusible penis armed with spines or hooklets. Various glands are associated with it. Vesicle in single or paired condition is often present and acts as the reservoir for storing sperms. The female reproductive organs consist of one or two *ovaries*. The oviducts when paired fuse distally and form a *common oviduct* which opens into the copulatory apparatus. The copulatory apparatus consists of a sac, the *seminal vesicle* or *seminal bursa* or *copulatory bursa*. Various glands which help in the formation of egg-shells and production of secretory substances are also associated with the copulatory apparatus. A long tubular or branched *uterus* for the purpose of accumulating ripe eggs forms a conspicuous part of the reproductive system. The female gonads in platyhelminthes is peculiar as it is distinctly differentiated in two zones, the ovary proper and the yolk or vitelline glands.

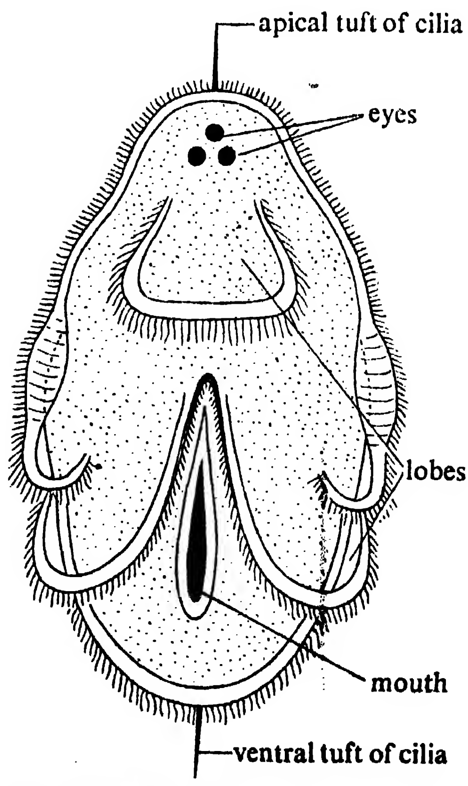


Fig. 13.22. Muller's larva (after Borradaile).

The yolk is never incorporated into the structure of the egg as in the case of other animals but it is produced as abortive eggs to be included inside the egg capsule or shell to provide food for the developing embryo. In cestodes the reproductive organs are repeated in each proglottid. In young proglottids the organs are rudimentary while these are highly developed in the gravid ones.

DEVELOPMENT

Though hermaphrodite, the practice of cross-fertilization is the rule. Fertilization is internal and fertilized, shelled eggs containing embryos are shed to the exterior. Acoela and Polyclads lack yolk glands and development is direct. In Polyclads a free-swimming larva is produced which is supposed to foreshadow the Trochophore. The larva is called *Muller's larva* or *Protrochula* (Fig. 13.22). It is oval in shape and bears eight prominent arms which are beset with long cilia forming one continuous band. General body surface is covered with small cilia. The mouth aperture is located in the mid-ventral line and three eyes exist in the anterior part of the dorsal surface. During development the ciliated arms are absorbed. In other groups the embryonic development is greatly modified and complicated.

SUMMARY

1. Bilaterally symmetrical, triploblastic and dorsoventrally flattened animals are included in this phylum.

2. Segmentation or metamerism is absent.

3. Skeletal structure in any form is absent.

4. Body cavity or coelom in true sense is absent and the spaces in between different organs are packed with a peculiar type of tissue called parenchyma.

5. Definite organ formation has occurred in this group but many systems like blood vascular and respiratory are absent.

6. Flame cells are associated with excretory system.

7. Reproductive system is very well-developed and most species are monoecious.

8. Majority members are parasitic and very few are free-living.

9. Poor development of some systems and enormous development of reproductive organs are due mostly to the parasitic mode of life or adaptation.

CHAPTER 14

Phylum Nemathelminthes (Nematodes)

This group includes the second largest number of metazoan forms. They are free-living or parasitic. Parasitic forms occur both in plants and animals. They exhibit a little of structural advancement over platyhelminthes in having insignificant body cavity and a complete alimentary canal (Fig. 14.1).

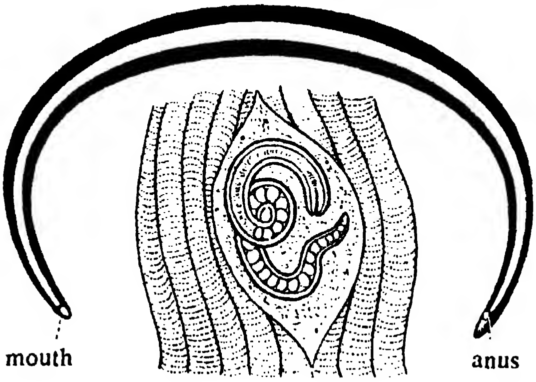


Fig. 14.1. Nematodes exhibit definite advancement over platyhelminthes in having complete alimentary canal. Some forms possess a space called coelom in between mesoderm layers.

IMPORTANT FEATURES

1. Nematodes are unsegmented, bilaterally symmetrical and round in cross-section. 2. Body is triploblastic and perivisceral cavity is more extensive than that in platyhelminthes. 3. Body is generally covered with thick cuticle. 4. Alimentary canal is provided with distinct mouth and anus. 5. Muscular system is well-developed. 6. Blood vascular system is absent. 7. Excretory system consists of a pair of lateral canals opening anteriorly by a single pore. 8. Sexes are separate. In males anus acts as generative aperture while in females the generative aperture is situated in the anterior ventral region. Sperms cells are amoeboid. 9. Life history is generally complex.

Classification

Nematodes exploit diverse habitat. They may be free-living or phytoparasitic or zooparasitic. Nematodes have been studied by few Zoologists, as a consequence the phylogenetic affinities of this group is not well-established. In the 7th Edition of the book entitled, "Text Book of Zoology—Parker & Haswell; Vol. I" the nematodes have been placed in the class NEMATODA under one of the pseudocoelomate phyla, ASCHELMINTHES because of the presence of :

(i) Pseudocoelome,

(ii) Cuticle covering the body,

(iii) Non-muscular straight gut with a terminal anus.

EXAMPLE OF THE PHYLUM NEMATHELMINTHES—*ASCARIS*

It belongs to the phylum Nemathelminthes and class Nematoda. The basic structural body plan of the nematodes is so constant that a good grasp of nematode anatomy can be obtained by studying a typical and common round worm, *Ascaris lumbricoides*, which is found in man.

Habit and Habitat

It resides as an endoparasite in the small intestine of man. The worm may migrate into other neighbouring channels. The parasites are most frequent in tropical and subtropical countries.

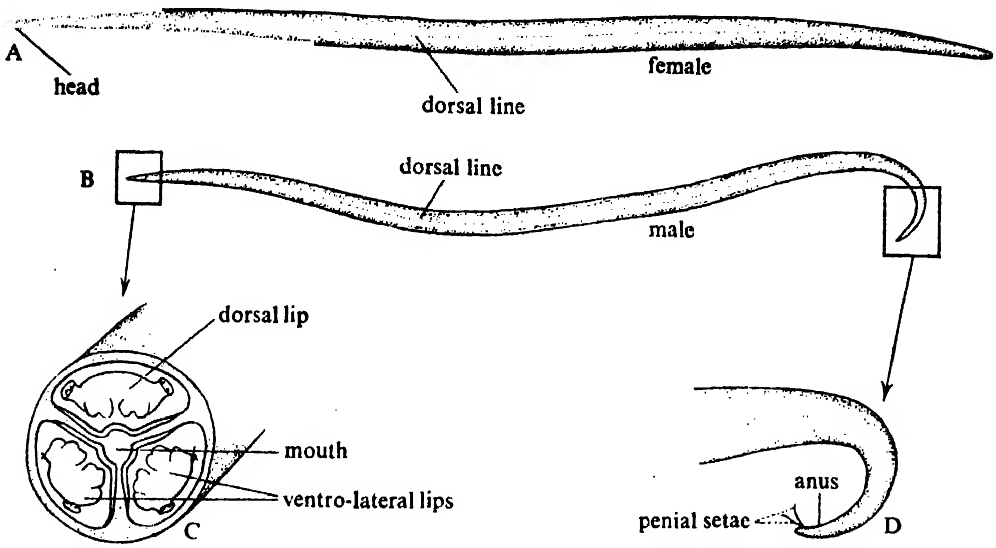


Fig. 14.2. External features of *Ascaris* (after various sources). A. Male. B. Female. C. Enlarged view of head end. D. Enlarged view of posterior end of male.

Structures

It is milk-white in colour but presents a reddish-yellow shade when alive. Female worms are larger than the males and are further distinguished by the presence of separate and independent *genital aperture* situated on the ventral surface at about one-third of the body length from the anterior (Fig. 14.2). Sexes can also be distinguished externally by the shape of the post-anal portion of the body. The post-anal portion in the male is sharply curved downwards while in the female it is nearly straight. Females are usually 20–25 cm in length and 5 mm in diameter while the males are 15–17 cm in length and 3 mm in diameter.

The body is cylindrical and tapering at both ends. The *mouth* aperture is anterior and terminal in position and is bounded by *three lips*, one median and dorsal and two ventro-lateral in position. A little upon the ventral side of the posterior end is situated the *anus* which is transverse in position and in males it serves also as the reproductive aperture. In males a pair of needle-like chitinoid bodies project from this aperture which are called *penial setae*. A little down the anterior tip and on the ventral surface is situated an *excretory pore*. The *female genital aperture* is situated on the ventral surface at about one-third of the body length from the anterior end. There is no male *genital aperture*. The body is marked with four *longitudinal streaks* or

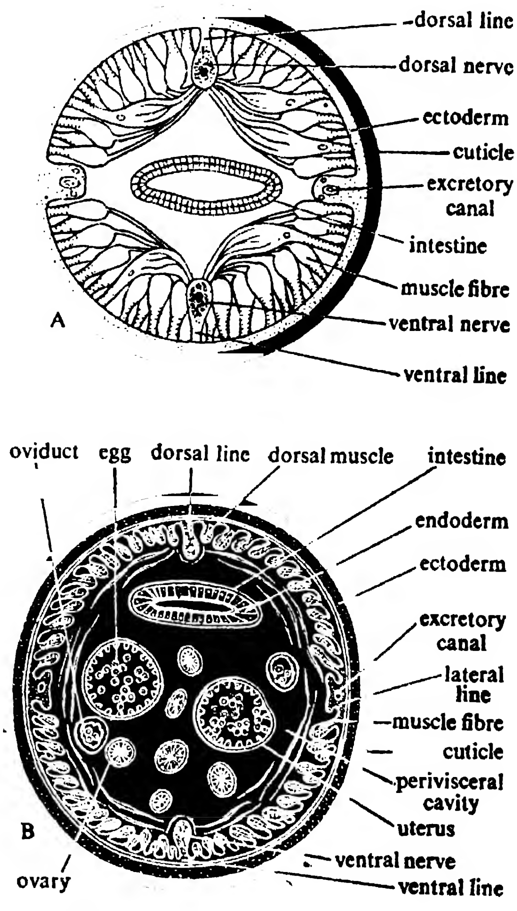


Fig. 14.3. Transverse section of *Ascaris* passing through anterior third (A) and through middle region of female (B) (after various sources.)

lines running along the entire length of the body. Of these four streaks one is *dorsal*, one is *ventral* and two are *lateral* in position. The dorsal and ventral streaks are narrow and pure white in living condition while the lateral ones are thick and brown in colour.

Body wall

The outer surface of the body is furnished by *cuticle* which is thin, transparent, delicate and wrinkled transversely (Fig. 14.3). The cuticle is secreted by the ectoderm. The *ectoderm* underneath the cuticle forms a syncytial protoplasmic layer. Below the ectoderm is a single layer of *longitudinal muscles*. The individual cells of the longitudinal muscles are very peculiar in appearance (Fig. 14.4). Each cell is spindle-shaped, straightened longitudinally and bears at the middle a bladder-like mass of protoplasm containing the nucleus which faces the side of the body. This peculiar appearance is due to the differentiation of the cell into a contractile and a nuclear part. The longitudinal muscle layer is not continuous and is arranged into four longitudinal bands, two *dorso-lateral* and two *ventro-lateral*. This is due to the fact that the ectoderm projects inwards at the dorsal, ventral and two lateral sides between the muscles to give rise to the streaks on the outer surface of the body.

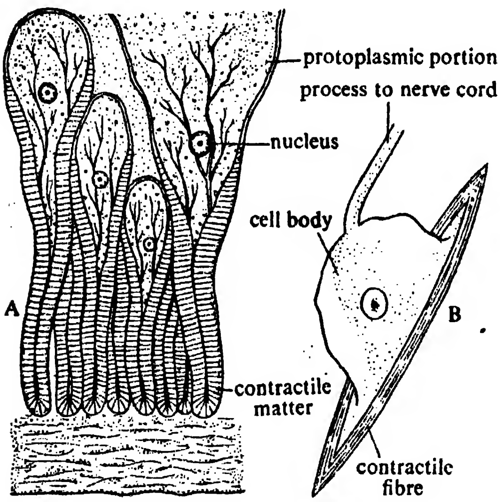


Fig. 14.4. Showing the muscle cell in transverse section (A) and an isolated muscle cell (B) of *Ascaris*.

Body cavity

The body cavity is not a coelom in the true sense as it is not lined by cell layers derived from the mesoderm. The body cavity is lined externally by fibrous processes of the longitudinal muscle cells and internally by cuticle encasing the intestine.

Digestive system

The mouth is anterior and terminal in position and leads into a straight tube which runs along the entire length of the body (Fig. 14.5A). The mouth is guarded by three lips. Behind the mouth is *buccal cavity*, which leads into *pharynx*. The pharynx is dilated and its wall is muscular.

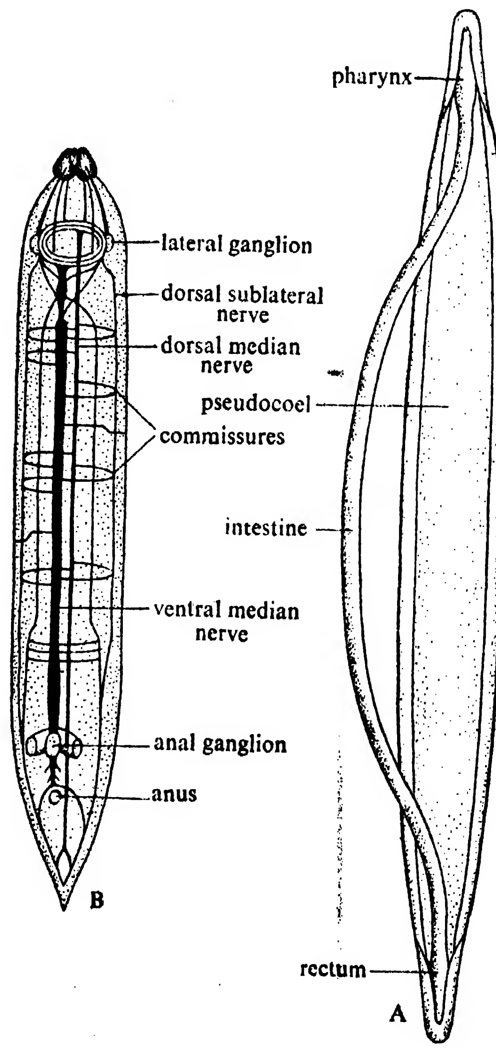


Fig. 14.5. A. Alimentary system of *Ascaris*. B. nervous system of *Ascaris* (after Kaestner).

The pharynx draws food from the intestinal contents of the host. It leads to the *intestine*. The posterior part of the intestine narrows down to form the *rectum* which opens to the outside through *anus*. The entire alimentary canal is made up of single *epithelial layer* covered internally and externally by *cuticle* derived from ectoderm. Digestive glands of any kind are absent.

Excretory system

The excretory system consists of two *longitudinal excretory canals* one through each lateral line (Fig. 14.6A). The two canals unite with each other at the anterior end and open to the outside through the single is an intracellular tubular extension of a single enormously elongated cell.

Nervous system

The nervous system consists of a ring of nervous matter round the pharynx (Fig. 14.5B). The ring is swollen at the ventral side and is ganglion-like. The ring gives off *six nerves* to the anterior and *six nerves* to the posterior side. Of the posterior nerves, two are of considerable thickness and run along the dorsal and ventral lines up to the posterior end of the body. The *dorsal* and *ventral longitudinal* nerves are connected with each other by *transverse commissures*. The tip of the ventral nerve

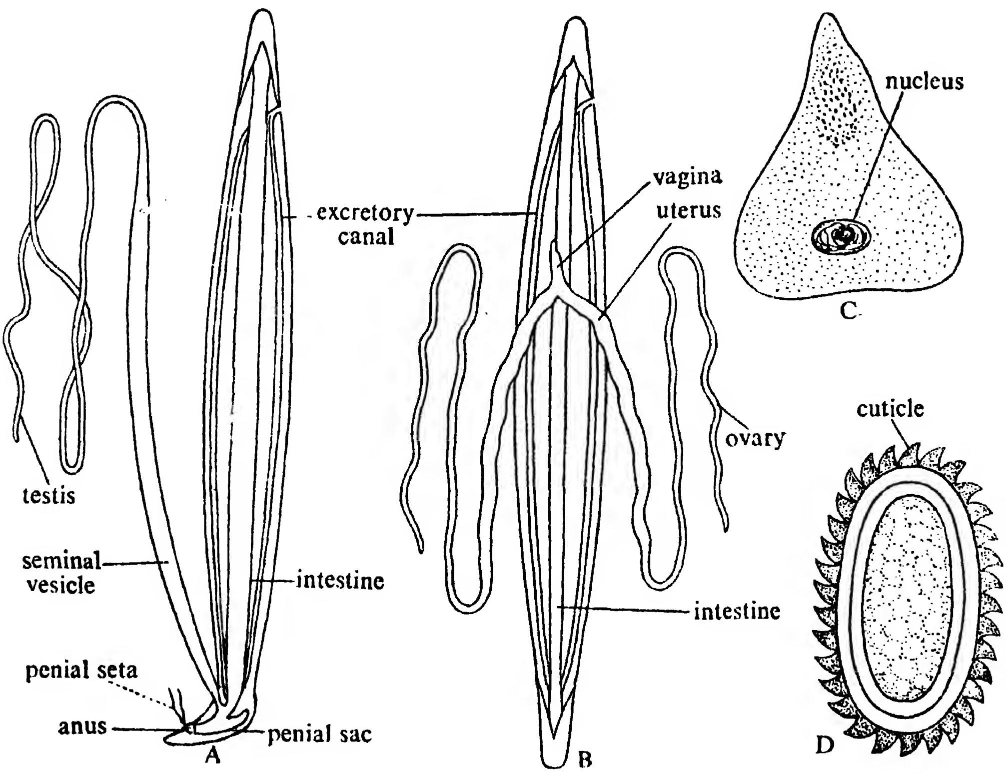


Fig. 14.6. A. Showing the excretory system and male reproductive system of *Ascaris*. B. Female reproductive system of *Ascaris*. C. Spermatozoon of *Ascaris*. D. Egg of *Ascaris*.

excretory aperture situated on the ventral side. Four to six big tufts of cells with ramifying protoplasmic processes remain in close contact with the canals. It is believed that these cells collect, store and pass on the waste matter in dissolved state to the excretory canal. The whole system is neither a ciliated one nor there is any flame cell. It is presumed that the canal

cord swells and forms a *ganglion* just in front of the anus.

The only sense organs are the *sensorypapillae*situated as small elevations on the lips.

Reproductive system

The sexes are separate (Fig. 14.6) and there exists a considerable degree of sexual dimorphism (Fig. 14.2).

Male Reproductive Organs. Male reproductive organs consist of a single thread-like, much-coiled structure occupying some portion of the body cavity. This structure is differentiated at the anterior region as the *testis*, the middle region as the *vas deferens* and the posterior region as the *seminal vesicle*. The demarcations between these three parts are very poor. The seminal vesicle continues as the *ejaculatory duct* and opens into the *anus*. The opening is associated with a pair of chitinoid spicules called *penial setae*, each of which is provided with a *muscular penial sac*. The anus, in case of male Ascaris, is used for the elimination of faeces as well as of sperms and in some way it resembles the *cloaca* of toad.

The sperms of Ascaris are very peculiar as they show amoeboid movement inside the body of the female. A ripe sperm is cone-shaped in appearance having a broad base and an apex (Fig. 14.6C). The apex contains the acrosome and the broad base contains nucleus and mitochondria. The sperms remain non-motile in the male gonoduct.

Female Reproductive Organs. Female reproductive organs consist of a pair of much coiled thread-like *ovaries* which pass into a *uterus*. The two uteri unite and form a muscular *vagina* which opens to the outside by the *female genital aperture* situated on the ventral surface at about one-third of the body length from the head.

Life history

Eggs are produced in huge numbers (20,000 a day) and are fertilized in the upper part of the uterus while the parasites remain in the intestine of the host. After fertilization each egg becomes enclosed in a chitinous egg shell.

Liberation of fertilized eggs. Shelled eggs without being segmented come out of the body of the host along with the faeces. Formation of embryo becomes completed in about two weeks.

Infection. Infection is direct, i.e. intermediate hosts are not involved. Infection results from ingesting fully developed embryos encased in shells along with food or drink.

Hatching. The embryos are not hatched in the stomach and pass on to the intestine where they hatch within two hours. Hatching is probably due to mechanical injury of the shell and is not comparable to a biological hatching.

Transformation to adulthood. A newly-hatched larva burrows the intestine and enters the *lymphatic ducts* or *veinules*. From the lymphatic ducts it is carried to the *mesenteries*, *lymph nodes* and from there to the *portal vein* through circulation. From the portal vein the larva comes to the *liver* through hepatic veins. Here they pass from interlobular to intralobular veins and are carried to the right side of the *heart* from where they are carried to the *lungs*. Development and moulting take place in the alveoli of lungs and then they come down to *intestine* through trachea and oesophagus. The journey takes about ten days and adulthood is reached in about two months time.

Pathogenic effects. Heavy infection produces:

(*i*) Volvulus by aggregation and intestinal obstruction;

(*ii*) Obstruction of Eustachian tube;

(*iii*) Appendicitis, Peritonitis, etc.

OTHER NEMATODES

WUCHERERIA BANCROFTI. Causative agent of the disease *elephantiasis* in which the limbs and other organs grow to enormous size (Fig. 14.7). Man is the definitive host and for the completion of life cycle an intermediate host, a species of mosquito is needed. Species belonging to genus *Culex*, *Aedes* and *Anopheles* all act as intermediate host. The worm is widely distributed but the distribution is not even. It is more prevalent in coastal areas of Africa, Asia and the United States. In Asia it is prevalent on the coasts of Arabia, India, Malay, Formosa, northern part of China and Japan.

Minute larvae called *microfilaria* inhabit the large blood vessels during day time and come to the small vessels in the skin at night. Microfilaria is about 0·2 mm in length. The cuticle of microfilaria is thin and striated and bears underneath a single layer of subcuticular cells. The head end is blunt and bears a clear cephalic space and rudiments of adult buccal cavity with oral stylet. The caudal end is pointed and without nuclei. The body column is provided with *somatic cells* being interrupted

at intervals by cellular and nuclear land marks. The relative positions of these land marks are definite in their body and they cause no trouble to man even if numerous.

When taken up by mosquitoes, the larvae pass to the stomach of the insect and then to the thoracic muscles. Metamorphosis of the larvae occurs inside the muscles and metamorphosed larvae enter the proboscis of the mosquito. The larvae enter the body of man along with mosquito bite and crawl to the lymph vessels. They coil up in the lymph gland and later mature. Adult worms are long and hair-like. Sexes are separate. The male is about 40 mm in length and 0·1 mm in diameter. The females are double the size of the males. The tail of the male is curved and there are two spicules of unequal length. The body tapers to a slightly swollen head and

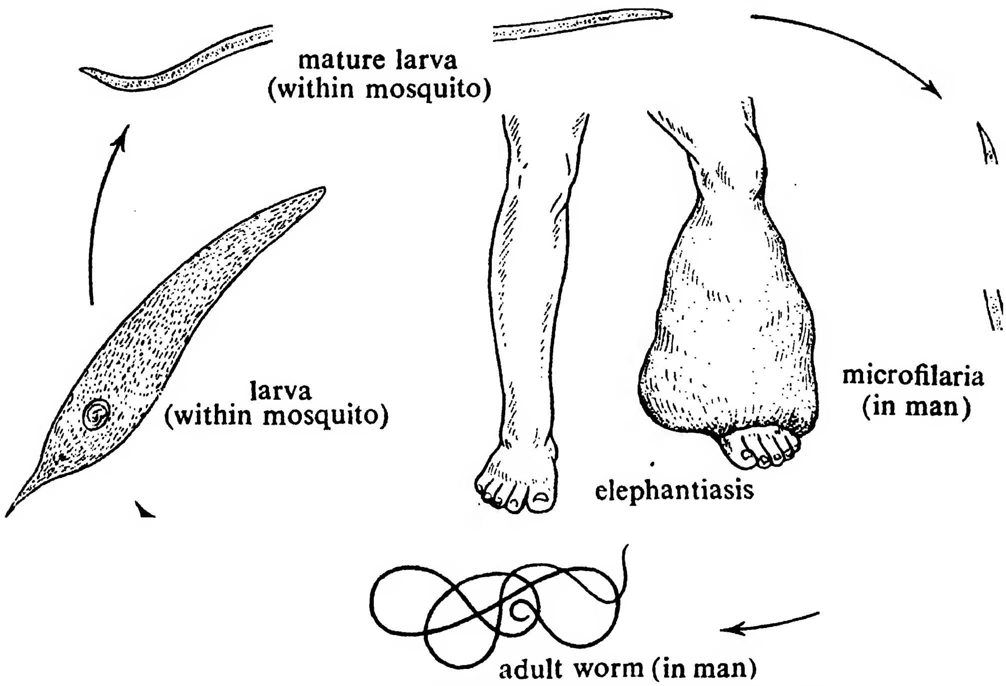


Fig. 14.7. Life cycle of *Wuchereria bancrofti* (after Storer and Usinger).

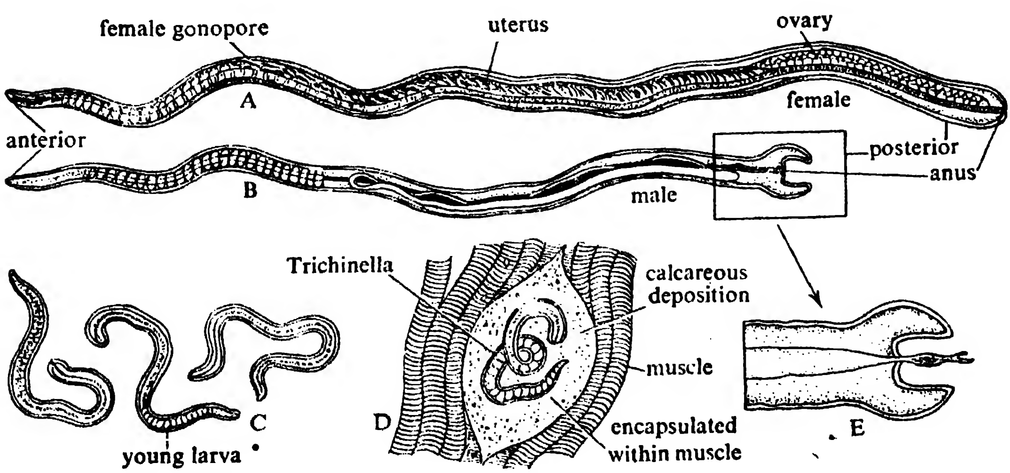


Fig. 14.8. Various stages of *Trichinella*. A. Female. B. Male. C. Young larvae. D. Encapsulated within muscle. E. Enlarged posterior end of male (after various sources).

bearing *mouth* as a simple pore. The oesophagus is partly muscular and partly glandular. The vulva opens a little behind the middle. If both sexes are present, they copulate and each female produces about 1000 microfilaria. Adults obstruct lymph circulation and ultimately *elephantiasis* is produced.

TRICHINELLA SPIRALIS. It is one of the deadliest parasites of man and occurs as minute larva encysted in the striated muscles of pig, man, dog and cat (Fig. 14.8). Sexes are separate, males measure about 1 mm and females about 3 mm. The worms are viviparous. Cysts enter into the stomach of the host along with meat, which is not properly cooked. On dissolution of the cyst, larvae are liberated into the intestine of the host and in about two days they become mature and they copulate. The male dies after copulation and the female burrows into the intestinal wall, releases about 1,500 larvae and perishes. The larvae enter lymph spaces and then are carried to the skeletal muscles by blood stream. They grow, coil up and secrete calcified cyst walls round them. The disease caused by the parasites is called *Trichinosis* in which muscles become swollen, hard and painful.

ANCYLOSTOMA DUODENALE. Ancylostoma duodenale, the Old World hookworm is a very common nematode parasite (Fig. 14.9) in the small intestine of

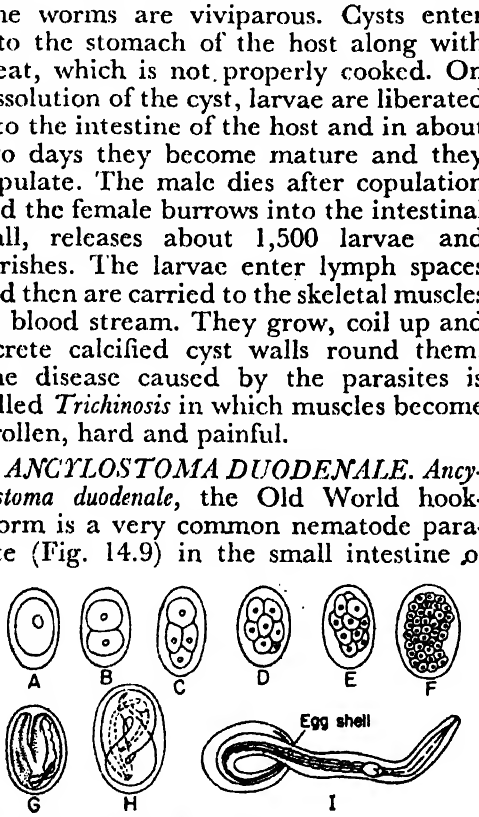


Fig. 14.9. Development of *Ancylostoma*. A. Fertilized egg. B–F. Segmentation. G. and H. Embryo within egg-shell. I. Hatching from egg-shell.

man. It belongs to the family Ancylostomidae. The adult worms anchor the wall of the small intestine by their anterior ends. The mouth is provided with sharp teeth by which wounds are afflicted in the intestinal wall at the region of attachment. Through these wounds blood comes out and the worms then suck the blood by the action of suctorial pharynx. Coagulation of the blood is prevented by the production of a secretion from the mouth which has an anticoagulatory property and thus blood is prevented from being coagulated. *A. duodenale* is recorded to suck profuse quantity of blood and the rate of sucking of blood is recorded to be 0·8 ml in 24 hours.

The mature male and female worms are different in size and their structural constructions are more or less similar to that of *Trichinella spiralis*. One peculiar feature is the presence of a pair of pear-shaped bodies called *cervical glands* on either side of the pharynx. The function of these structures is not known. The adult worms measure about 8-13 mm in length. The male and the female worms mate in the intestine. A single female is estimated to produce few thousands of eggs per day. The eggs from the intestinal cavity are expelled to the exterior with the faeces. The eggs in warm and moist places transform into the larvae, within 24-48 hours. The larvae measuring 0·5 mm in length, are the infective stages which enter the host body by penetrating through the naked skin, particularly through foot. The larvae then enter the veins and travel through heart, lungs, trachea, oesophagus and finally reach the intestine. The larvae, after reaching here, undergo two successive moults and attain maturity in due course.

The hosts infected with Ancylostoma become anemic as a result of considerable loss of blood from the intestinal wounds caused by the hookworms. Besides the anemic condition, the hosts become susceptible to all diseases, particularly tuberculosis because of the damage done by the larvae during their transit from the heart to the final abode. As a preventive measure the following suggestions can be made:

1. The most important is the sanitary disposal of human faeces to prevent pollution of the earth.

2. The hookworm infection can be checked by administering tetrachlorethyl or hexylresorcinol.

ENTEROBIUS VERMICULARIS. Popularly known as pinworm and infects children. The adult worms are very small in size and inhabit the intestine, caecum and appendix. Sexes are separate. The gravid females migrate to the rectum and produce itching sensation. Eggs are laid

in the rectum and infection occurs by bodily transference of eggs.

DRACUNCULUS MEDINENSIS. Commonly known as Guinea-worm and man is its final host. Young ones occur in a shrimp-like form of crustacea called Cyclops. The cyclops are ingested along with drinking water and the young parasites are liberated into the stomach from where they migrate to subcutaneous tissues. Males measure about 4 cm and die after copulation. The females are about 12 cm in length and gravid females have two uteri full of fertilized eggs. For laying of eggs the females come to the superficial layer of the skin and die after discharging eggs.

CLASSIFICATION

The classification of Nemathelminthes is a Herculian job considering the number of individuals included in the phylum. The classification still remains in a chaotic state. Parker and Haswell have considered it as one of the members of five non-coelomate classes of animals.

CLASSIFICATION IN OUTLINE

To avoid complexities it is better to remain restricted to certain important orders:

Order *Ascaroidea*, e.g. *Ascaris*.
Order *Oxyuroidea*, e.g. *Enterobius*.
Order *Strongyloidea*, e.g. *Ancylostoma*.
Order *Filaroidea*, e.g. *Wuchereria*.
Order *Dracunculoidea*, e.g. *Dracunculus*.
Order *Trichuroidea*, e.g. *Trichuris*.

CLASSIFICATION WITH CHARACTERS

Order *Ascaroidea*. Large stout nematodes residing in the intestine of vertebrates as parasites; mouth is provided with 3 prominent lips; males possess 2 equal or almost equal copulatory spicules; tail of females is blunt; oviparous, e.g. *Ascaris lumbricoides*; *Ascaris megalocephala; Ascaris suilla.*

Order *Oxyuroidea*. Small to moderate in size; parasites of vertebrates; copulatory spicules are present in males; tail of females is long, narrow and pointed; caudal expansion or alae is present; life cycle is simple and revolves round one host, e.g. *Enterobius vermicularis* (Pinworm), *Thelastoma.*

Order *Strongyloidea*. Lips are absent; males with two spicules; a true copulatory bursa is present, e.g. *Ancylostoma duodenale* (Hookworm), *Trichostongylus* (Hairworm).

Order *Filaroidea*. Thread-like; moderate to large in size; females are larger than males; lips are absent; males with two unequal copulatory spicules but do not have bursa or caudal alae; oviparous or viviparous; parasites of vertebrates and with a blood sucking invertebrate as intermediate host, e.g. *Wuchereria bancrofti* (Filaria), *Loa loa* (eye-worm), *Onchocera.*

Order *Dracunculoidea*. Thread-like; females are larger than males; spicules of males are of same sizes; no bursa in males; adult females are with degenerated bursa; mostly viviparous, copepods as intermediate hosts, e.g. *Dracunculus medinensis* (Guinea-worm), *Camallanus.*

Order *Trichuroidea*. Anterior part of the body whip-like; males with one or without spicule; males are either with bursa or with cirrus; life cycle simple—no intermediate host, e.g. *Trichuris, Trichinella spiralis.*

GENERAL NOTES ON NEMATHELMINTHES

HABIT AND HABITAT

The Nemathelminthes are popularly known as 'Round worms' and sometimes called 'Nemas'. They are among the most structurally simple of all worms because practically all of them depict materially the same basic body plan. Great number of nematodes are free-living and extend from north to south pole and at the same time there exists a formidable array of parasitic forms living both on plants and animals. In fact, every plant and metazoan animal has its quota of nematode parasites. The parasitic forms cause unimaginable damage to crop and domestic animals. So far as the absolute number of nematodes are concerned they are second to none than the insects and outnumber the insects in the variety of ecological nitches they occupy. A survey of the abundance of nematodes in different sites gives the following figures:

(*i*) Roots of a single potato plant contain more than 40,000.

(*ii*) Intertidal muddy sand of sea has about 5 million/sq. metre.

(*iii*) Aerable land has up to 6 billion per acre.

Despite their superabundance in certain sites, the nematodes are never conspicuous and are not noticed for the reason that majority of them are of microscopic sizes.

Free-living nematodes are saprozoic and feed on plant and animal remains. Some feed on yeast and bacteria. Few members prey on small protozoa and rotifers. Parasitic forms are provided with spines or teeth around the mouth which are used in piercing. None of the nematodes can engulf large particles. And in all essentialities they are microphagus or juice feeder. The food habits of nematodes offer an opportunity to visualise evolution in action because with little imagination one can easily realise how saprophagus and herbivorous forms have given rise to plant parasites and saprozoic types have been evolved into animal parasites.

The nematodes exhibit maximum tolerance of environmental variations. They possess the power to withstand extreme cold, heat and dessication. The vinegar eel (*Turbatrix aceti*) living in vinegar (5% acetic acid) can thrive successfully up to a concentration of 14% acetic acid. Living nematodes have emerged from mosses which have been re-wetted after keeping them dried for about 5 years. The shelled eggs are much more resistant and remain viable for years. The eggs of Ascaris can withstand prolonged immersion in 12% formaldehyde, saturated solutions of mercuric chloride and in many toxic salts. Embryonic stages are usually less resistant.

STRUCTURE

There exists a considerable similarity of organisation and shape in different nematodes. General shape of the body as the name implies is round, cylindrical and tapering at both ends. The length usually varies from 0·4 m (Ascaris) to 1 m (Dracunculus). The largest of all nematodes is *Placentonema gigantissima.* The females of this species attain a length of 8·5 m, the diameter being 2·5 cm and they parasitise the placenta of sperm whales. The females of all nematodes are generally larger than the male.

BODY WALL

On the outer surface of the body wall there is a cuticle which is hard and flexible. It is resistant to many solvents and gastric juices. Next to the cuticle lies the ectoderm. In some forms like Ascaris the ectoderm is represented by a syncitial protoplasmic mass. Beneath the ectoderm only longitudinal muscles are found. The individual cells of the muscle fibres are very peculiar. They are elongated and may reach a length of 10 mm. One end of the cell is contractile while the other end which houses the nucleus is non-contractile. The non-contractile part keeps contact with a nerve fibre. The longitudinal muscle layer is not continuous and is arranged into four longitudinal bands. Two of these bands are dorso-lateral while the other two are ventro-lateral in position.

In some free-living species the ectoderm bears unicellular glands. These glands help the animals to attach themselves to the substratum.

BODY CAVITY

Body cavity is not a true coelom because it is not lined by epithelial layer derived from mesoderm. Some workers have called it 'Pseudocoelom'. According to them, the absence of mesenchyme in between the body wall and digestive tract has stood in a good way for the evolution of a more organised digestive system. The pseudocoelom is filled with a fluid and the fluid acts as a 'hydrostatic skeleton'.

DIGESTIVE SYSTEM

Digestive tract is complete. The mouth is situated at the anterior end of the body and remains surrounded by lips. In the basic plan there are six lips. But as seen in Ascaris the number of lips is reduced to three due to fusion. In some forms there may be many lips due to splitting. The mouth leads to a buccal capsule. The capsule is cuticular and the inner wall of the capsule in some cases forms plates. The capsule may house three or more teeth. In some cases a hollow 'Stylet' is formed inside the capsule by the fusion of these teeth. The buccal capsule leads to the pharynx. The pharynx, like the buccal capsule is also cuticular. The lumen of the pharynx is triangular. The pharyngeal wall is a syncytium of radial muscle

fibres and the wall contains many one-celled glands. In some, the pharynx acts as a sucking apparatus. Pharynx leads to the intestine. Intestine is straight and is made up of a single layer of epithelium. Rectum is short and opens into the anus. The anal opening is on the ventral surface of the posterior end of the body.

most advanced forms anterior elongation of the excretory tubule has been lost resulting an inverted 'U'-shaped system. The evolution of 'U'-shaped excretory system from Renette cells is encountered during the embryonic development of many parasitic nematodes (Fig. 14.10).

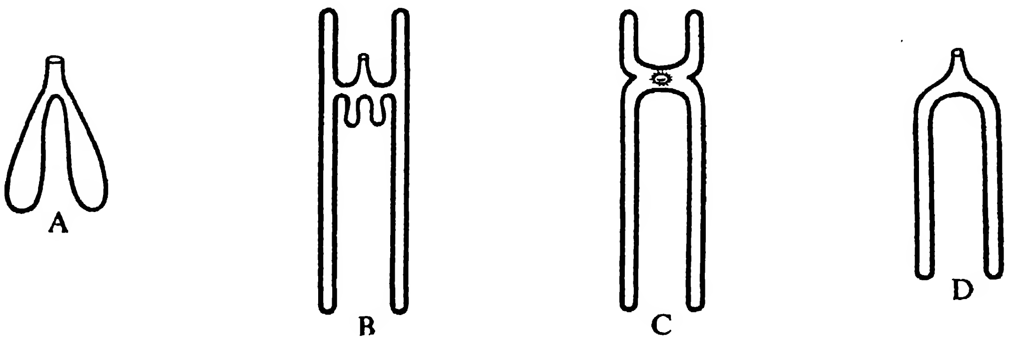


Fig. 14.10. Showing the evolution of inverted 'U'-shaped excretory system from Renette cell. A. Renette cell. B and C. 'H'-shaped in intermediate forms due to tubular outgrowths from the cells. D. Inverted 'U'-shaped due to degeneration of the anterior prolongation of the tubules (after Fingermann).

The anus is cuticular and in some forms like Ascaris it acts as a cloaca in males only. The intestine is much reduced in *Mermis*. Feeding habits of nematodes are variable. Free forms may be herbivorous, carnivorous or saprophagous. Parasitic forms live on the nutrients inside the host's intestine or in the blood and disintegrated tissues of the host.

EXCRETORY SYSTEM

Excretory system of nematodes is very different from other animals as it does not show any phylogenetic relationship to the protonephridial system of platyhelminthes or to the excretory system of any other higher phylum. The pseudocoelom in primitive forms houses a very peculiar cell called 'Renette cell'. It is a glandular cell with a tubular neck. In primitive forms a pair of such cells open to the exterior through the excretory pore situatted on the ventral surface of the anterior end. It is believed that the prevailing type of excretory system in advanced nematodes is an evolutionary outcome out of the primitive Renette cell. Bilateral arrangement of these cells together with tubular outgrowths from the cells has given rise to a 'H'-shaped system in some intermediate forms like Oxyurida, Ascarida. In

RESPIRATORY AND CIRCULATORY SYSTEMS

There is no special organ or organ system for respiration and circulation. The cuticle serves as the respiratory surface. Few intestinal parasite like Ascaris can live on oxygen in young stage but in adult stage they get oxygen by anaerobic splitting of nutrient materials present inside the intestine of the host. To send the endproducts of digestion to the cells of the body wall and other parts there is no special organ for circulation. Endproducts of digestion are absorbed by the intestinal epithelium and from there they are passed onto the fluid of the pseudocoelom. From the fluid of the pseudocoelom nutrient materials reach the cells of the body wall.

NERVOUS SYSTEM

The nervous system is of simple type and consists of a 'brain' or nerve ring from which nerves extend to the anterior and posterior parts of the body. The nerve ring is present round the pharynx and is formed by two lateral pairs of ganglia. From the ganglion a ventral nerve cord extends along the mid-ventral line and ends in a ganglion above the anus. Dorsal motor nerve and three pairs of lateral sensory nerves are also present.

REPRODUCTIVE SYSTEM

In nematodes sexes are separate. Adult males are smaller in size than the females and in most males the posterior end of the body is curved. Male reproductive system consists of a single thread-like much coiled structure. The anterior part of the coil forms the testis, middle part forms the vas deferens and posterior part forms the seminal vesicle. The seminal vesicle continues as the ejaculatory duct and opens into the anus. Inside the anus there is a pocket which contains a pair of eversible penis spicules. That means there is no male gonopore. The sperms are cone-shaped and have a broad base and a tapering apex. The sperms show amoeboid movement inside the body of the female.

The female reproductive structures consist of a pair of ovaries, a pair of oviducts and a pair of uteri. The two uteri unite to form a vagina which opens to the outside by a single female genital aperture situated on the ventral surface of the body. In Trichinella, the female reproductive structure is single.

DEVELOPMENT

Eggs are fertilized in the vagina of the female. Soon after fertilization the eggs become enveloped by three membranes—an outer albuminous covering, a middle chorionic covering of chitinous nature and an inner vitelline membrane. In hookworms the outermost layer is absent. Cleavage is of determinate type. In Ascaris the first cleavage divides the egg into a somatic cell and a germ cell. Blastula is a coeloblastula. Epiboly is the usual mode of gastrulation. In Ascaris and Trichuris fertilized eggs leave the body of the mother and host before segmentation. Segmentation starts outside the body and later on it becomes infective. In *Enterobius* the eggs leave the body of the mother and host in segmented condition. In *Ancylostoma*, the eggs leave the body of the mother and host in partially segmented condition.

PARASITIC ADAPTATION IN HELMINTHES

Adaptation to environments is one of the dynamic features of living organisms. Of the different categories of adaptations, parasitic adaptation is important since it presents a peculiar condition in which a fortituous free-living existence is altered to one in which protection from enemies and a good supply of food are guaranteed. This parasitic adaptation has brought about profound modifications in the helminthes.

Transformation from external to internal

Parasitism undoubtedly began as a chance of contact of one organism with another. Sooner or later the guest began to partake the food procured by the host, becoming more and more dependent on such food and in many instances became gradually changed from an ecto- to endoparasite.

Two important aspects of parasitism as encountered in the helminthes

The structural and functional modifications in parasites depend on the degree of parasitism. In a successful parasitic group of animals the modifications run in two distinct directions—one leads to loss or degeneration while the other leads to gain or new attainment.

A. Degeneration

The degeneration in helminthes particularly involves the locomotor and digestive organs. As the parasites live on the digested or semidigested food of the host, their organs of locomotion and alimentation have become simplified. They are mostly useless.

(1) *Organ of locomotion*

Total reduction of locomotor organs is observed in adult except in the free-living larval phase when the ectoderm becomes ciliated, e.g. Miracidium and Hexacanth of flatworm.

(2) *Organ of alimentation*

(*a*) Total disappearance in the adult tapeworm;

(*b*) In the hermaphroditic adult trematode it consists of a blind gut;

(*c*) In Redia stage it is further simplified and completely eliminated in the Sporocyst stage.

B. New attainment

(1) *Integument*. The integument covering the body of helminthes has become greatly

modified to serve following three important functions:

(*a*) Absorption. The phenomenon of absorption is striking in larval stages which develop in the lymph spaces of mollusca or in blood stream, muscle fibre or musculature of vertebrates (Cysticercus, Trichinella) and in the adult blood flukes in the hepatic portal system and in various species of liver flukes in the bile tract. In these cases, the entire integument becomes thin and undoubtedly serves partly or fully as a means for food absorption.

(*b*) Protection against the digestive juice of the host. In the case of the larval flukes which have to pass through stomach in order to reach the bile passage for further development—a cyst capsule is provided as a protection against the digestive juice.

Certain Amphistomes (in Ruminants) and Gnathostomes (in cats, dogs and horses) remain attached to the stomach wall. They are provided with thick resistant integument impregnated with chitin-like substances of impermeable nature.

(*c*) Protection against abrasion. Many trematodes living in the intestinal tracts are provided with spinous integument to guard against the abrasive action of the food and roughage passing through the gut. These spines may be of *accicular*, *dentate* or *placoid* types and are rooted into the subintegumental layer.

The oriental liver fluke *Clonorchis sinensis*, which was probably an intestinal parasite before it became a bile duct inhabitant, possesses a spinous integument during its larval phase—in fact until it becomes safely located in the bile passage.

(2) *Modification for attachment*. Essential prerequisite for parasitic life is the possession of suitable mechanism to attach strongly with host body.

Following modifications for attachment are often encountered:

(*a*) Acetabulum or sucking organ. Found in all the adult flatworms which parasitise man.

(*i*) In the flukes it consists of two suckers on the ventral side of the body—one anterior and the other posterior to it.

(*ii*) In the case of human tapewarm, it consists of either sucking tongue or groove, or four cups at the cephalic end of the worm.

(*b*) Hooks. In some tapeworms and nematodes, hooks are situated in or around the anterior end.

(*i*) In Taenia, hooks are arranged in double circlet at the base of rostellum.

(*ii*) In the dog tapeworm, it occurs in several rows around the proboscis which may be everted.

(*iii*) Hooks are often provided with series of teeth and are placed in the buccal capsule.

(*iv*) In *Macracanthorhyncus* sp. a buccal armature of tooth-like structure is present, which serves for tissue aberration and anchorage.

(*c*) Glands. In some of the helminthes there have been developed in the vicinity of mouth, secretory glands which serve in

(*i*) anchorage in favourable habitat, and
(*ii*) aid in food supply.

(*iii*) In trematodes these glands are more common in the Cercarial stage and serve the purpose of penetration to host tissue by elaborating histolytic substances.

(*iv*) In hookworms—there are glands in buccal region which are supposed to have anti-coagulative property.

(3) *Modification for reproduction*. The most conspicuous elaboration in organs and tissues in the helminthes is that of the reproductive system.

(*a*) Both Platy- and Nemathelminthes have large part of their body mass occupied by these organs and their products.

(*b*) The adult flatworms, with few exceptions, are hermaphrodite.

(*c*) The roundworms are dioecious.

(*d*) Adult flukes and tapeworms have particularly complex reproductive organs. In both the groups, cross-fertilization, which was formerly the rule and is still a possibility, has been superseded by self-fertilization.

(*e*) In tapeworm, instead of a single body unit, there are multiple segments—proglottids, each one is sexually complete in itself.

C The Unaltered systems. Two systems of organs—the nervous and excretory, have remained almost unchanged. However, the excretory system in the case of flatworms has undergone some insignificant changes.

Greatest modifications among the helminthes have been encountered in such forms that reside in the blood or lymph systems (blood flukes and filarial worms) or in the muscular tissue (Trichinella) or forms that attach to the peritoneum (Hydatid cyst). They have been reasonably designated as old parasites while those forms which live in mouth or bladder of the host or on the body surface (Monogenic trematodes) have been termed young parasites as demonstrated by their relatively slight modifications from the prototypes of the group.

Viewing the groups of parasitic helminthes as a whole with respect to successive stages of adaptation which they have undergone and are undergoing, one is able to appreciate the vastness and profoundness of the principles of adaptations and at the same time how marvellously the parasitism has become successful in helminthes.

SUMMARY

1. Nemathelminthes stand second as regards the number of individuals in a phylum. Some workers have placed diverse type of nematodes in the class Nematoda under the phylum Aschelminthes. The members of the phylum are free-living as well as parasitic.

2. They are adapted to diverse habitats.

3. The basic body plan in all nemathelminthes is almost similar.

4. Nematodes are round, thread-like, unsegmented and bilaterally symmetrical.

5. Body is covered over by a thick cuticle.

6. Body cavity is a pseudocoelom.

7. Cilia in any form are absent.

8. Alimentary canal is complete, straight and it begins in mouth and ends in anus.

9. Sexes are separate. Females are larger than the males. In males the anus also acts as the generative aperture.

10. Classification of Nemathelminthes is in a chaotic state.

CHAPTER 15

Phylum Annelida

This is a widely distributed phylum having great diversity in form and structure. Many annelidan features like segmentation, nephridia, etc. form the basis on which the interpretations for the evolution of structures of still higher forms rest (Fig. 15.1).

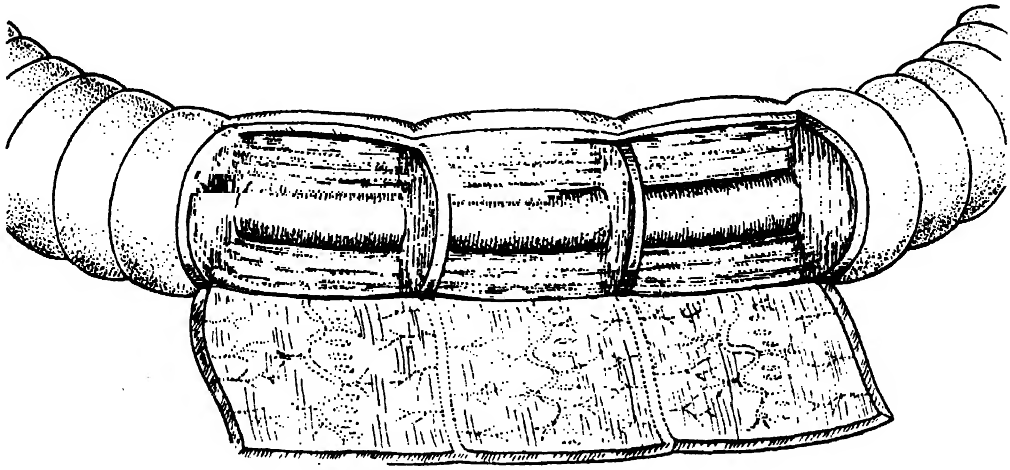


Fig. 15.1. Annelids are triploblastic coelomate metazoa in which the body is metamerically segmented, i.e., partitions split the body into compartments, both internally as well as externally.

IMPORTANT FEATURES

1. In annelids the body is cylindrical and elongated. 2. The body is made up of metameres or segments and the segments are usually marked both externally and internally. 3. The body cavity is a true coelom. 4. A system of blood vessels is present in most forms. 5. Excretory organs are metamerically arranged pairs of coiled tubes called nephridia. 6. The animals are often provided with coelomoducts which are channels for the outward passage of reproductive elements. 7. Nervous system is well recognised and in most cases it is represented by cerebral ganglia and double ventral nerve cord with segmentally arranged ganglia.

CLASSIFICATION IN OUTLINE

Phylum Annelida includes three classes: *Chaetopoda*, *Hirudinea* and *Archiannelida*. Myzostomidae is considered as an appendix to the class Chaetopoda while Echiurida and Sipunculida are appendices to the phylum Annelida.

EXAMPLE OF THE PHYLUM ANNELIDA—*NEREIS* (*NEANTHES*)

Habit and Habitat

Nereis is a member of the class Chaetopoda. It is a marine animal. It lives on the seashores at the intertidal zone. Throughout the world they are seen in innumerable number under crevices in sands and stones or within sea-weeds. The type which is described here is known as *Nereis dumerilii*.

External Structures

The body is approximately 7–8 centimetres in length. The colour is light violet and the regions of the body which are richly supplied with blood vessels appear reddish. The glittering appearance of the surface is due to the intersection of two sets of fine lines. The animal is long, narrow and cylindrical (Fig. 15.2). The body is divisible into about 80 segments or metameres and a distinct head is present at the anterior end. All the segments excepting

the head and the last segment bear laterally placed, muscular and movable paired appendages called *parapodia* (Sing. *Parapodium*). The terminal segment is

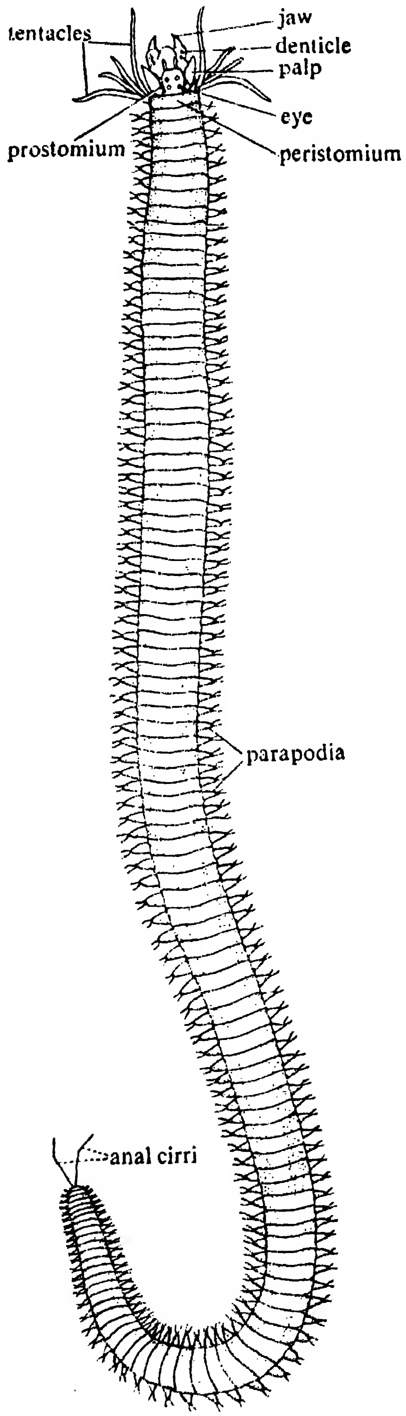


Fig. 15.2. External features of *Nereis*—dorsal view (after Bloom and Krekeler).

termed as the *anal segment* and it bears at its posterior end a small round opening, the *anus* or *pygidium*. Anal segment bears a pair of *anal cirri*. On the ventral surface and near the base of the parapodium lies a nephridial aperture. Thus a pair of nephridiopores is present in each parapodial segment.

STRUCTURES IN THE HEAD. The head is divisible into two parts: *prostomium* and *peristomium* (Fig. 15.3). The prostomium bears following structures.

(1) PROSTOMIAL TENTACLES—paired, cylindrical, small and placed in front. (2) PALP—paired, elongated and compact. Located after the tentacles. (3) EYES—two pairs, round, pigmented and present on the dorsal side of the head.

The peristomium carries (1) PERISTOMIAL TENTACLES—four pairs, long, slender, cylindrical and laterally placed. (2) MOUTH—present on the ventral side as a transverse aperture.

STRUCTURES OF THE PARAPODIUM. All the segments excepting the first and the last segment bear on either lateral side a fleshy, flat and hollow parapodium. Largest parapodia are encountered in the middle segments of the body, then the size of the parapodia decreases towards the two ends. Each parapodium is biramous in nature. It consists of a basal part and two distal parts—(1) dorsally placed *notopodium* and (2) ventrally placed *neuropodium* (Fig. 15.4). Both these parts are subdivided into lobes and both of them carry pack of needle-like structures called *setae* (sing. *seta*) which project beyond the lobes. The dorsal and ventral sides of the parapodium bear small, tentacle-like, cylindrical appendages, called *dorsal* and *ventral cirrus* respectively. The ventral cirrus, situated ventral to the neuropodium is smaller than the dorsal cirrus situated dorsally on the notopodium.

SETA. The setae are stiff, needle-like chitinous rods which remain in bundle within a sac in the skin. The sac is known as setigerous sac. The entire bundle may be moved in various directions with the help of muscles. One of the setae in each bundle is long, rod-like and dark in colour. It is known as *aciculum* and it projects on the surface. Each seta consists of a basal *shaft* with which articulates a terminal *blade*. Three types of setae are seen (Fig.

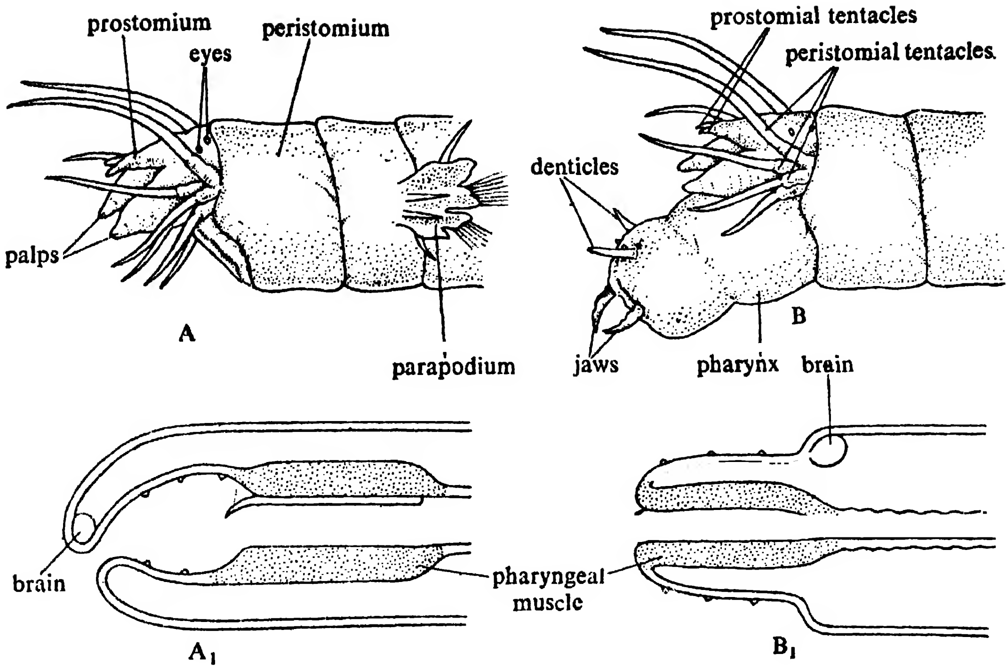


Fig. 15.3. *Upper row*, Magnified view of the head of *Nereis*. A Pharynx in usual position. B. Pharynx everted during feeding. *Lower row*, Diagrammatic sectional view of the head to show the disposition of pharynx during retracted (A_1) and everted (B_1) condition (after various sources).

15.5). (1) In one type the shaft is oar-shaped. (2) In the second type shaft is slender and the blade in narrow, straight and elongated. (3) In the other type the shaft is comparatively thicker and the blade is small and curved.

Body wall

The body wall is divisible into (*a*) *cuticle*, (*b*) *epidermis*, (*c*) *muscle layers* and (*d*) *parietal epithelium* (Fig. 15.6). The details of each part is discussed below:

(*a*) Cuticle. It is thin, slightly brittle and chitinous having a network of fine lines on the external surface which renders an 'iridiscent lustre'. Number of minute openings are present on the cuticle through which the epidermal glands open to the exterior.

(*b*) Epidermis. This is formed by a single layer of cells. It is more thick on the ventral side specially near the parapodial joints. The dorsal side of the epidermis is richly supplied with blood vessels. Number of 'twisted' unicellular glands are present specially on the ventral side.

(*c*) Muscle layers. The outer muscular layer is *circularly* arranged and the inner layer runs *longitudinally*. The longitudinal muscles are present in four bundles—two are *dorso-lateral* and the remaining two are *ventro-lateral*. The circular muscles of dorsal and ventral sides are interconnected by two strands of *oblique muscles*.

(*d*) Parietal epithelium. It is a part of the coelomic epithelium which lines the outer wall of the coelom or body cavity. It is made up of a single layer of cells.

Body cavity or Coelom

The body of Nereis in transverse section looks like a tube within a tube. The wall of the outer large tube is the body wall and the wall of the inner small tube is the gut wall. In between the two walls, lies a spacious cavity called coelom or body cavity, which is filled up with a fluid. The coelom is thus lined externally by *parietal epithelium* (inner layer of the outer tube) and internally by *visceral or splanchnic epithelium* (outer layer of the inner tube). The coelom is divided into compartments by transverse partitions called *septa*. The wall of each septum is perforated through which coelomic fluid communicates from one chamber to the other.

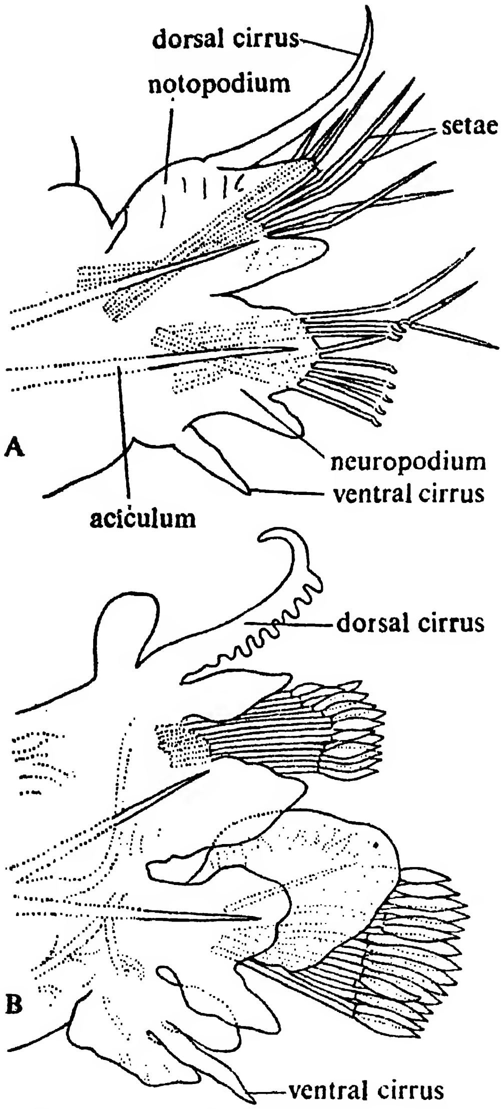


Fig. 15.4. Structure of parapodia—A. *Nereis*. B. Heteronereis stage. Note the modification of parapodium in heteronereis stage for swimming (after Kaestner).

Digestive system

The alimentary canal begins from mouth and runs straight to end in another aperture called anus. The presence of two openings (mouth and anus), for inlet and outlet respectively, shows a marked advancement over platyhelminthes where only one aperture served the double purpose. The gut wall exhibits following histological structures—(1) outer *visceral epithelium;* (2) next one layer of *longitudinal muscles* followed by another layer of *circular muscles;* and (3) innermost layer of *enteric epithelium.* The alimentary canal consists of following parts:

(*a*) Mouth. It is present on the ventral side of the peristomium as a transverse aperture and opens to the buccal cavity.

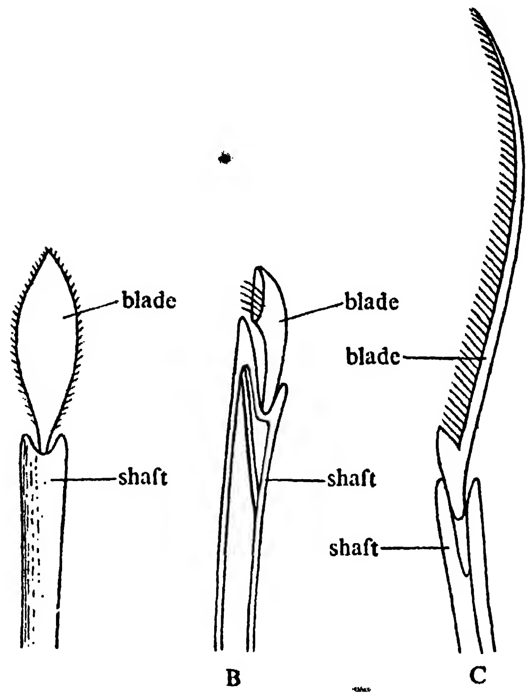


Fig. 15.5. Different types of setae—A. Oar-shaped seta. B. Typical seta. C. Long bladed seta (after various sources).

(*b*) Buccal cavity. It is a broad chamber with cuticular lining. The cuticles have been thickened to form *teeth* or *denticles* or *paragnaths*. The buccal cavity leads into the pharynx.

(*c*) Pharynx. It extends up to the fourth segment and is also lined internally by cuticle. One pair of cuticular teeth are enlarged to form jaws at the posterior end of pharynx. The jaws are extended along the longitudinal axis of the body and are round at the base and pointed at the apex. The base is provided with muscular attachment while the inner edge of the apex is serrated. Special bands of protractor and retractor muscles are present in the pharyngeal region. The protractor muscles evert the buccal cavity and pharynx as proboscis and the retractor muscles withdraw it. The pharynx leads to the oesophagus.

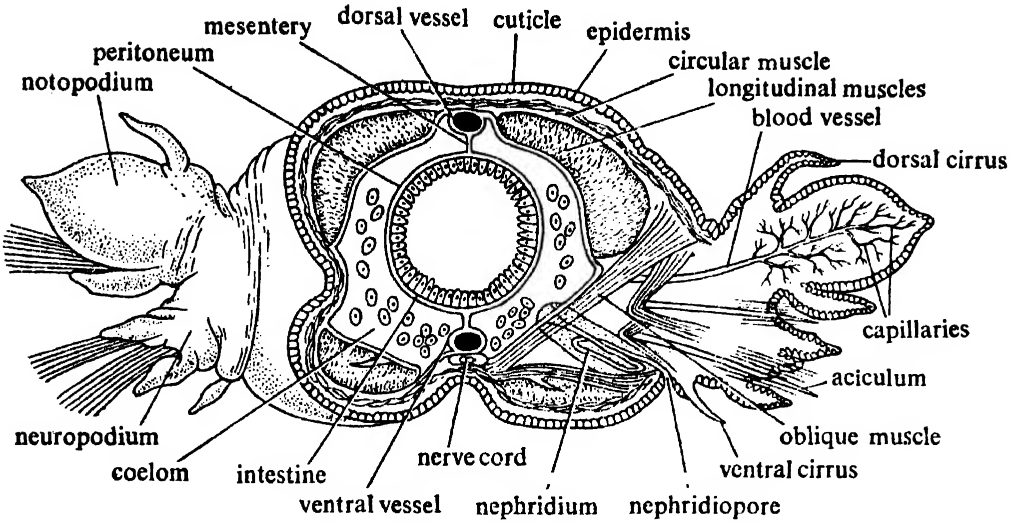


Fig. 15.6. Diagrammatic view of different structures in a segment of *Nereis*. Left side of the figure depicts an entire parapodium and the remaining part is shown in cross-section (after various sources).

(*d*) Oesophagus. It traverses through next five segments and receives a pair of large glandular caeca. The oesophagus communicates with the intestine.

(*e*) Intestine. It is a more or less straight tube which is constricted at each segment. The constrictions are intense at the posterior end.

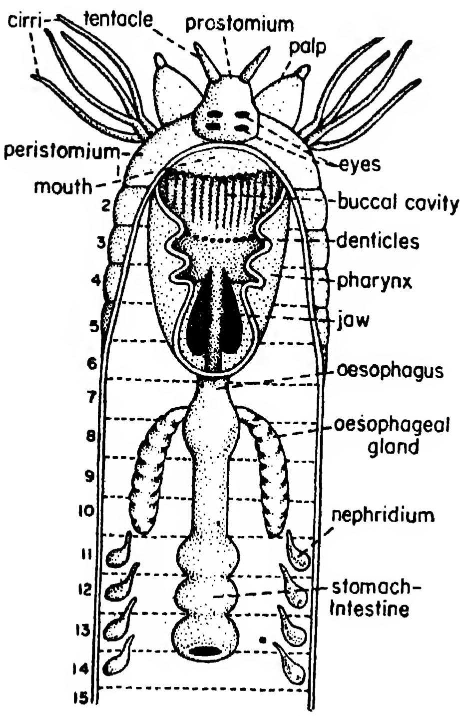


Fig. 15.7. Digestive system of *Nereis*.

(*f*) Rectum. In the last segment, intestine continues as rectum. It is lined internally with cuticle and opens to the exterior through an aperture called *anus*.

Developmentally, the buccal cavity, pharynx and rectum originate from the ectoderm which also forms the outer covering. And for this reason, like the outer wall, these are also lined by cuticle.

Mechanism of Feeding. Nereis is carnivorous and devours small animals like crustacea and small molluscs. It seizes the food by means of jaws and teeth. The entire bucco-pharyngeal region during capture of prey, is everted out. The eversion is caused by the pressure of coelomic fluid and contraction of protractor muscles. When this happens the buccal cavity becomes turned inside out while the pharynx is thrown forward so that the jaws are opened and come to lie in front of the head. The folding in of the buccal cavity and pharynx is caused by contraction of retractor muscles and relaxation of protractor muscles. Another type of Nereis (*Nereis diversicolor*) exhibits two different mechanisms of food-capture. Sometimes the animal comes out of its burrow and ingests small and nutritious particles from the surface of mud. On other occasions, it remains within the burrow and secretes mucus. Then by the undulations of the

body it draws a current of water into the burrow. The mucous cone acts as a sort of net where small particles carried in with water are strained off. Then, at intervals, the animal engulfs the net.

Respiratory system

Gills are absent in Nereis. The function of respiration is taken over by the lobes of parapodia and dorsal integument. For this reason, these regions are richly supplied with blood vessels. The physiology of respiration is known in *Nereis virens*. It lives at a depth of 20–30 cm and in almost oxygen-free sand. The animals draw water by producing water current while gaseous exchange takes place through the vascularised regions of the parapodia. When the oxygen pressure in surrounding water is equal to the oxygen pressure of blood, gaseous exchange ceases. This arrest of respiratory exchanges is possible by restricting the blood flow only to the dorsal and ventral vessels. Nereis draws nearly 75% of the oxygen from water.

Circulatory system

Blood of Nereis is red in colour. The constituents of blood are plasma and corpuscles. Haemoglobin remains dissolved in plasma and its quantity is 8–9 mg per cubic millimeter. The blood flows through definite blood vessels (Figs. 15.8 & 15.9). The chief blood vessels are:

A. Longitudinal vessels. There are three longitudinal vessels running along the entire length of the body. These are—

1. Dorsal blood vessel. This vessel serves as the main collecting vessel and runs mid-dorsally from one end of the body to the other end above the alimentary canal. It carries blood from posterior to anterior end.

2. Ventral blood vessel. It is the main distributory vessel running mid-ventrally from one end of the body to the other below the alimentary canal. It conveys blood from anterior to posterior end.

3. Neural blood vessel. This is a delicate longitudinal vessel accompanying the ventral nerve cord.

B. Transverse or commissural vessels. The dorsal vessel is connected to the ventral vessel in each segment by two pairs of transverse vessels. But this link is not direct. Transverse vessels originating from the ventral vessel first give off branches to the parapodia, alimentary canal and adjoining parts. Some of these branches ramify to form networks of fine vessels inside the parapodial lobes and in the integument of the dorsal surface. Then from these extensive capillary networks, stout vessels are formed which open into the dorsal vessel.

C. Segmental intestinal vessel. The ventral vessel gives off two pairs of intestinal vessels in each segment to form capillary network in the gut wall. From there blood is returned to the dorsal vessel by another two pairs of intestinal vessels.

Mechanism of blood circulation

Blood remains in constant circulation through the vessels by means of contractions which are *peristaltic* in nature. Waves of contractions transmit along the walls of the vessels to drive the blood. A series of ring-like muscle fibres round the walls of the blood vessels at short intervals aid in contraction. The contractions of the dorsal vessel are the most powerful. Dorsal vessel is the main collecting vessel and blood flows through it from

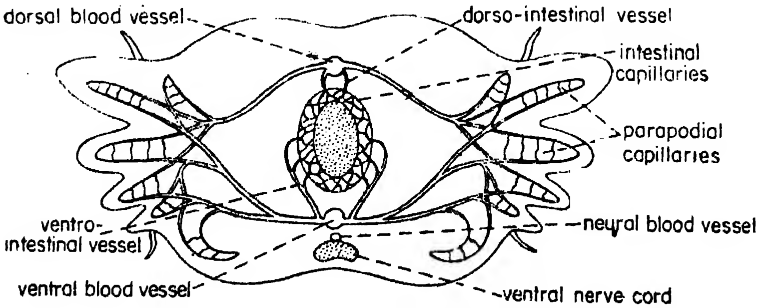


Fig. 15.8. Circulatory system of *Nereis*.

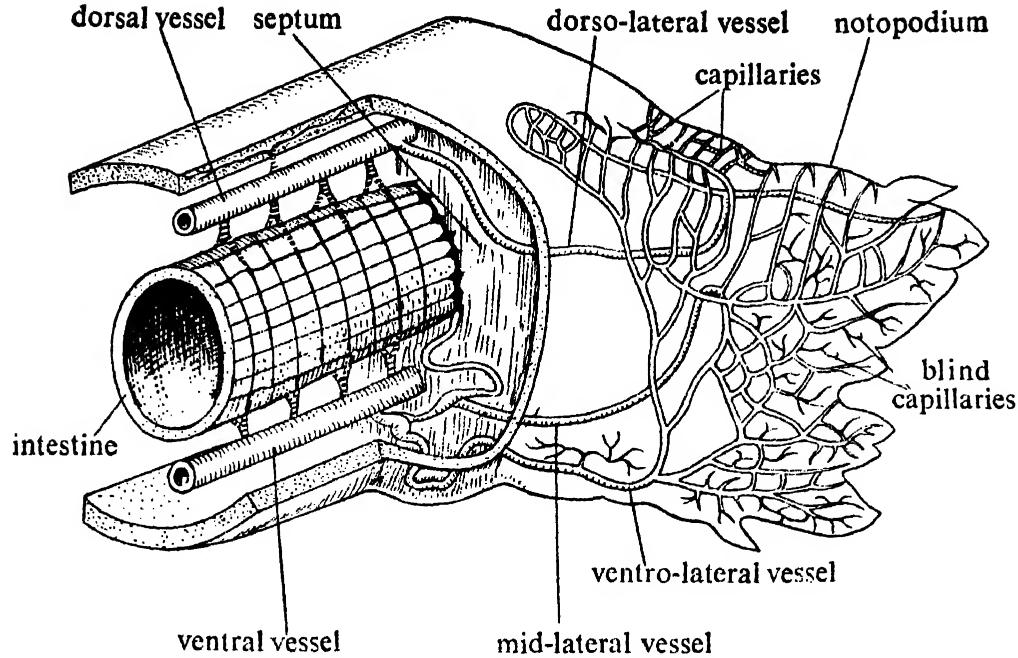


Fig. 15.9. Schematic representation of blood circulation in a segment of *Nereis* (after Kaestner).

posterior to anterior end. Whereas the flow of blood is in opposite direction through ventral vessel and by transverse and intestinal vessels it sends blood to the different parts of the body.

Excretory system

The excretory system consists of series of metamerically arranged paired tubes called *nephridia* or *segmental organs*. They are absent in the anterior and posterior segments. A nephridium is made up of three parts: (*a*) the *body*, (*b*) *anterior prolongation* of the body and (*c*) *coiled ciliated tube*.

(*a*) Body. The body is irregular in outline, oval in shape and lies at the base of the parapodium in a transverse fashion.

(*b*) Anterior prolongation. It is a continuation of the inner end of the body. The narrow prolongation is almost equal in length to the body and runs forward and inward to become attached to mesentery.

(*c*) Coiled ciliated tube. The coiled ciliated tube is housed in the body cavity and is the anterior prolongation of the nephridium (Fig. 15.10).

The external opening of the tube is called *nephridiopore*. It is a small, circular opening on the ventral surface of the body and at the base of the ventral cirrus of the parapodium. The diameter of the aperture may be extended or contracted. The nephridiopore leads into the tube which is

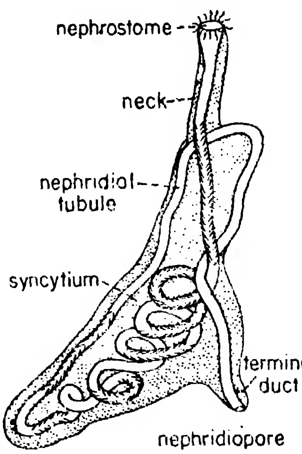
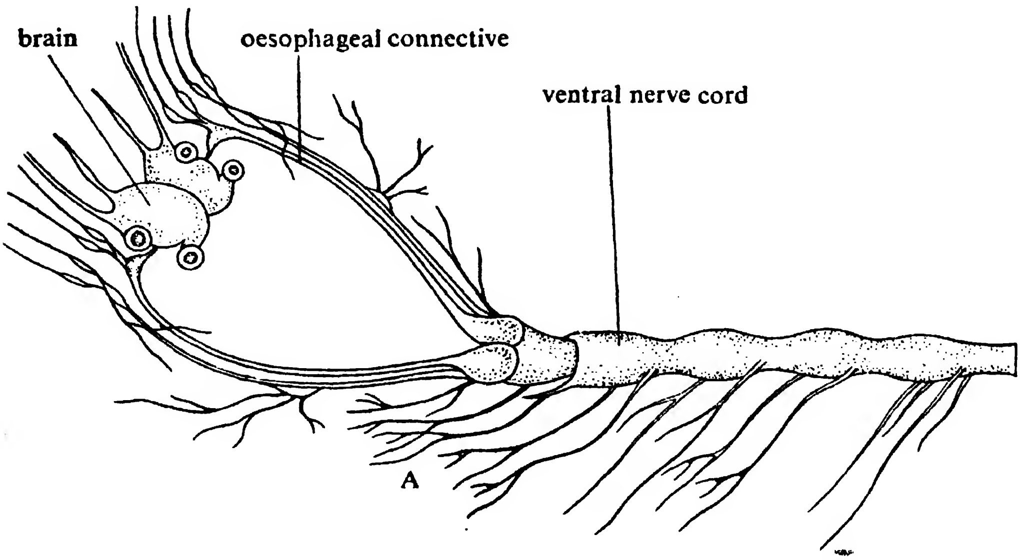


Fig. 15.10. Nephridiun of *Nereis*.

ciliated for the most part. The tube extends up to the tip of anterior prolongation and then takes a sharp turn to run into the body of nephridium. Inside the body, the tube follows a zigzag course and ultimately passes through the anterior prolongation to open as the *nephrostome* into the preceding segment. The nephrostome is funnel-shaped and its border is beset with a number of narrow ciliated processes.

DORSAL CILIATED ORGANS. Each segment bears on the dorsal surface specially developed ciliated tract of coelomic epithelium in the form of short funnels without external aperture. These are called *dorsal ciliated organs*. The specific role of these structures are not clearly understood. Some believe that they are excretory in function while others consider them as genital ducts of temporary nature.

A. **Central nervous system.** It includes: (1) CEREBRAL GANGLIA OR BRAIN. It is present in the prostomial region as a large bilobed mass (Fig. 15.11A). The brain contains specialised cells, which produce hormone to speed up regeneration. It has also been experimentally demonstrated that extirpation of brain leads to precocious sexual maturity. (2) OESOPHAGEAL CONNECTIVES. Two stout nerves,



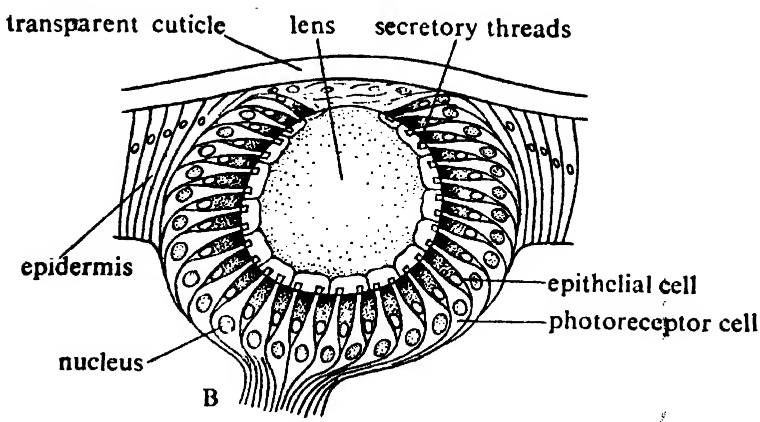


Fig. 15.11. A. Nervous system at the anterior region of *Nereis* (after Parker and Haswell). B. Sectional view of an eye of *Nereis* (after Kaestner).

Nervous system

The nervous system of Nereis consists of (A) *Central nervous system*, (B) *Visceral nervous system* and (C) *Sense organs*.

each originating from the posterior region of the brain turn around the two sides of the mouth and unite on the ventral wall of the pharynx. (3) VENTRAL NERVE

CORD. It originates from the ventral side of the pharynx, i.e. the region where two oesophageal connectives meet, and it runs posteriorly along the mid-ventral line. The ventral nerve cord is formed of two separate cords which are enveloped by a common connective tissue sheath. Along its path, the cord possesses a ganglion in each segment. The individual ganglion is also formed by the fusion of two ganglia. (4) PERIPHERAL NERVES. These are nerves given off by brain, oesophageal connectives and ganglia of the ventral nerve cord. From brain, nerves are supplied to the tentacles, palpi and eyes. The oesophageal connectives supply branches to innervate peristomeal tentacles. The ganglion on the ventral nerve cord sends nerves to the various parts of the corresponding segment.

B. **Visceral nervous system.** In addition to the nerves belonging to the central nervous system, another set of nerves is given off from the brain. These fine nerves with ganglia innervate the anterior part of the alimentary system. It is known as *stomatogastric* or *visceral nervous system*.

C. **Sense organs.** Following sense organs are present in Nereis:

(*a*) EYES. There are two pairs of eyes. Each eye is a cup-shaped and darkly pigmented structure. The concave side bears the *retina*, a circular aperture, *pupil* and a *lens* of gelatinous consistency (Fig. 15.11B). Many elongated and slender cells which are arranged parallelly form the wall of the cup. These cells through the union of their outer ends form the optic nerve and their inner ends extend towards the lens as clear and hyaline *rods*. The region of the cuticle which covers the eyes, acts as the *cornea*.

(*b*) OLFACTORY ORGANS. The olfactory organs are known as *nuchal organs*. These paired organs are present on the posterior and dorsal side of the prostomium and remain in close contact with the hinder part of the brain. Each nuchal organ has two pits lined with ciliated epithelium.

(*c*) TACTILE ORGANS. The tentacles, palpi and cirri are regarded as specialised tactile sense organs. With the help of specialised sensory cells they can discriminate the changes in the environment.

Reproductive system

Sexes are separate in Nereis but well-formed gonads in the form of testes or ovaries are not regularly recognised. The gonads develop by the proliferation of coelomic epithelial cells of the body cavity. The gonads are temporary structures and appear only in the breeding season. The males develop only a pair of testes which are present in any one of the segments between nineteenth and twentyfifth. The number of testes may be more in other species. During breeding season groups of cells pinch off from the testes into the coelomic fluid. These cells undergo division and each daughter cell develops into a sperm. The sperms have rod-shaped heads and vibratile tails.

Spherical ovaries in females appear along the entire length of the body. They are metamerically arranged and occur one pair in each segment. The ova (when young) become detached from the ovaries into the coelomic fluid where they attain maturity. Both ovaries and testes degenerate after the liberation of sex cells.

Mature reproductive cells are liberated probably through temporary apertures formed by the rupture of the body wall. Fertilization is external and occurs in sea-water.

STRUCTURAL CHANGES DURING GONAD FORMATION. The formation of gametes induces changes in the posterior half of the body. Such changes are noted in the critical appearance of lobes of the parapodia and in the number of setae in bundles. In addition, the prostomial eyes become enlarged and the terminal segment produces sensory papillae. The worms after such transformations are known as *Heteronereis*.

The heteronereis forms are free-swimming. The body is divisible into two distinct parts. The anterior or asexual part is called '*Atoke*' and the posterior sexual part is called '*Epitoke*'. The changes of the parapodia in the posterior half of the body are, first, increase in size and secondly, the formation of leaf-like outgrowths on the lobes. Bristles which replace setae remain inserted into the parapodium and assume fan-like appearance (Fig. 15.4B).

The transformation to the heteronereis form is due to the impact of hormones, released into the blood plexus from certain specialised cells, which remain very close

to the brain. Some authors, however, consider Nereis and Heteronereis as two distinct species.

Development. The matured egg has two enveloping membranes. The outer cover is thin and the inner one is broad with radial striations. With these membranes the egg remains within a covering of gelatinous consistency. Oil droplets and yolk bodies remain scattered throughout the cytoplasm of the egg. The fertilization or the entry of sperm cell brings following changes in the egg: (*a*) inner radiated layer dissolves, (*b*) egg completes the maturation phase by liberating two polar bodies, (*c*) egg exhibits irregular amoeboid movement and (*d*) considerable rearrangement of cytoplasmic particles occurs. This results into the shifting of oil droplets and yolk spherules towards the centre, thus leaving a side with granular cytoplasm and nucleus.

The zygote finally assumes spherical shape and starts to divide. This is called cleavage. First two divisions produce four cells. These cells are called macromeres. One macromere becomes larger than the other three. These macromeres divide unequally in three sets and thus give rise to twelve micromeres. At the end of first unequal division of the macromeres, four micromeres of equal sizes, are produced. The second unequal division of the macromeres produces four more micromeres, but this time three are of same sizes and one is large. The third unequal division of the macromeres again results three more micromeres of same sizes and one large micromere. During these unequal divisions of the macromeres, the micromeres are not produced at their tops. On the contrary, after first division the micromeres are pushed towards right, then during next division they shift to the left and again to the right. Such arrangement gives rise to a spiral pattern. The two large micromeres are known as *somatoblasts* or *mesentomeres.* The micromeres give rise to ectoderm, somatoblasts or mesentomeres result into mesoderm and macromeres produce endoderm layer. The micromeres spread over the macromeres and push them and somatoblasts inside. Further development involves transformation of these cells into the various structures of larva. The larva is known as *trochophore* larva (Fig. 15.12).

TROCHOPHORE LARVA. The larva is a small, oval or pear-like transparent organism. The anterior end of the body is broader than the posterior end and it exhibits bilateral symmetry. It has mouth, alimentary canal and anus. The mouth is situated near the mid-ventral line of the body and it leads into the alimentary canal which at the beginning proceeds transversely and then curves round to advance towards the narrow end. The canal ends in an anal aperture at the posterior tip of the body. Two prominent bands of cilia

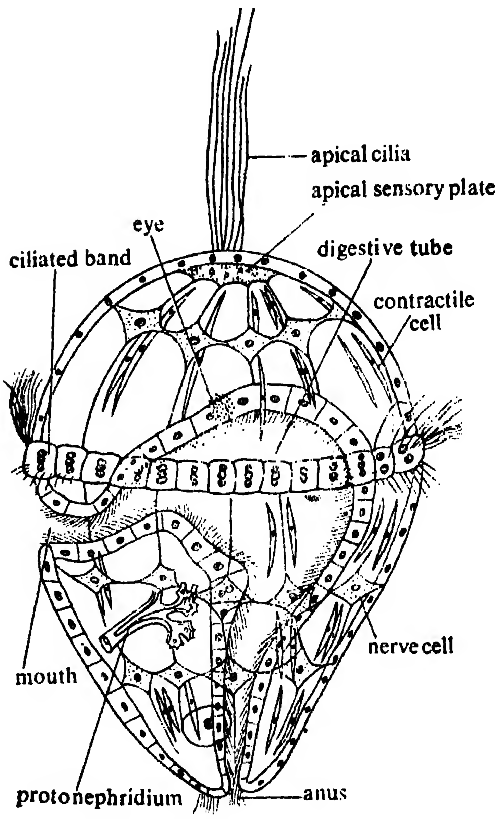


Fig. 15.12. Trochophore larva.

encircle the body and in certain forms a third band may be present. A double circlets of strong ciliary band called the *pre-oral circlet* or *prototroch*, encircle the body around the middle and just above the mouth. Behind the mouth a second circlet of cilia is present, *the post-oral circlet* or *telotroch.* The ciliated groove proceeds backward from it along the middle region of the ventral side. Trochophore exhibits no metamerism and the rudiment of future adult trunk is seen as a small region at the posterior pole. There is no coelom at this

stage but only a spacious blastocoel encloses the gut. Within the blastocoel, a pair of protonephridia, certain amount of mesenchyme and larval muscles are present. The upper pole possesses an *apical plate* with a number of long cilia.

The free-swimming larva feeds on the plankton and other microscopic organisms and transforms into an adult worm.

Similar larval form appears in the life history of many molluscs and in this respect Trochophore larva is considered to be very important from the evolutionary stand-point.

Affinities of Trochophore larva

Trochophore larva was first discovered by a Swedish Naturalist, Loven in 1840. Since then the larva was known as Loven's Larva. Later on Ray Lankestar (1877) gave the name Trochophore to this larval form. This larval form exhibits remarkable similarities with several other larval forms. As a consequence the phylogenetic status of Trochophore warrants serious consideration.

Affinities with Ctenophora. The aboral sense organ (Statocyst) of a ctenophore is compared with the apical sensory plate of trophophore. The sub-ectodermal radiating nerves are comparable. The prototorch is derived from fourth group of ciliated cells. Both of them have pear-shaped body. Despite the similarities the fundamental organisation portrays many diversities. The cleavage pattern is different in both the cases. The anus is absent in ctenophores. So the trophophore larva cannot be regarded as related to ctenophores.

Affinities with Muller's larva. The Muller's larva of Turbellarians, especially that of *Planocera* shows similarities with the trochophore larva. Similarity in developmental stage, similarity in the disposition of ciliated bands and presence of eye spots at the aboral end of the two larval forms led many wokers on this line to draw parallelism between the two groups. But due to undernoted dissimilarities the parallelism cannot be justified. The dissimilarities are: (*i*) absence of anus in Muller's larva, (*ii*) the enteron opening into one opening in Muller's larva, (*iii*) difference in the embryonic differentiation of mesoderm and (*iv*) the existence of tuft of cilia at the caudal end of Muller's larva.

Affinities with Pilidium (Nemertini) larva. The pilidium larva of Nemertini exhibits certain similarities with the trochophore larva. The similarities are : (*i*) both have helmet-shaped body, (*ii*) the ciliated ring between aboral and oral ends of pilidium larva represents the prototorch of trochophore, (*iii*) similarities in the disposition and distribution of nerve ring, (*iv*) the stomodaeum shows similarities, (*v*) the schizocoelic mode of formation of coelom in both. But the absence of anus in pilidium and the dissimilarities in the formation of mesoderm stand on the way to draw any relationship between them.

Affinities with Rotifera. *Trochosphaera*, a rotifer shows some similarities with the trochophore larva of annelid. Trochosphaera resembles trochophore in many respects, viz. ciliated girdles, disposition of nervous system ('Brain') and the sense organ, placement of anus, nephridia and curvature of intestine. But the resemblances are mostly superficial in nature and need critical examination to draw any phylogenetic relationship.

Affinities with Veliger larva. The preoral ciliated ring, ciliated tuft of flagella

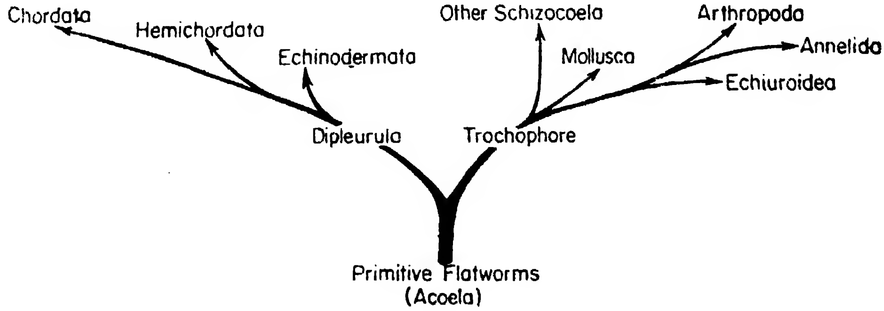


Fig. 15.13. Phylogenetic relationship of Trochophore larva.

and apical plate of the veliger larva of mollusca are similar with that of trochophore larva. The similarities between the trochophore and veliger larva are possibly due to remote phylogenetic convergence.

In the evolutionary dynamics of invertebrates the trophophore larva occupies a prominent status. It shows similarities with many invertebrate groups. The affinities throw light on the emergence of bilateral groups from the animals having radial symmetry (Fig. 15.13). It is claimed that the trophophore represents a transitional stage in the line of emergence of the bilateral groups (e.g. Rotifers) from the radial groups (Ctenophores). Similarities between the trochophore and the echinoderm larva (Bipinaria and Pluteus) and *Tornaria* larva of *Balanoglossus* added more weight to this contention.

Example of the Phylum Annelida—*EARTHWORM*

Habit and Habitat. The most common earthworm of our country is known as *Pheretima posthuma*. It is a member of the class Chaetopoda. Pheretima usually inhabits the moist soil. During day time they live in underground burrows and at night and rainy season they come out of their shelters. The castings of earthworms, which are small rounded pellets or balls, lie at the openings of the burrows. These castings are formed when the animals go deep into the hard and closely packed soil by 'eating' earth. The eaten-up earth passes through the body and are deposited as 'castings'. While burrowing, the earthworms make the soil loose and porous. The body wastes of earthworm increase soil fertility. So the earthworms are called the natural tillers of land.

External structures. The body is elongated, narrow and cylindrical (Fig. 15.14). The thickness of the body is more or less uniform. The anterior end is more pointed than the posterior end. The dorsal side of the body is brown in colour and can be readily distinguished from the ventral side which is brightly coloured. The impression of the dorsal vessel can be seen on the dorsal side as a dark median line extending throughout the length of the body. A full-grown worm measures about 20 cm in length.

The body of the animal is made up of distinct segments or metameres separated from each other by intersegmental grooves. The number of segments comprising the

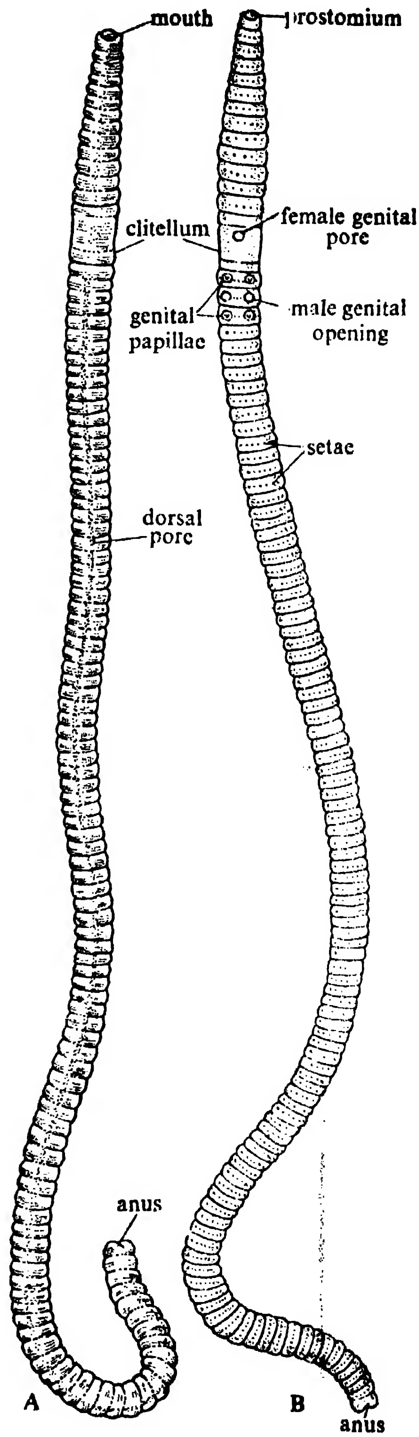


Fig. 15.14. Dorsal (A) and Ventral (B) views of earthworm.

body are about 100–120. This external segmentation corresponds to internal segmentation. The segments 14–16 from the anterior end are encased in a thick glandular tissue sheet called the *clitellum* (saddle) or *cingulum* (belt). Considering the clitellum as the index, the body may be divided into three regions, namely the *pre-clitellar*, *clitellar* and *post-clitellar* regions. Some of the anterior segments bear superficial furrows so that these segments appear to be subdivided. These are merely external subdivisions.

There is no distinct 'head' as in Nereis and the first body segment is called *peristomium* which bears the mouth aperture on its ventral surface. Overhanging the mouth on the dorsal surface is a small fleshy lobe, the *prostomium*, which is considered as a projecting part of the first segment and not a segment by itself (Fig. 15.15). The last segment bears the *anus*

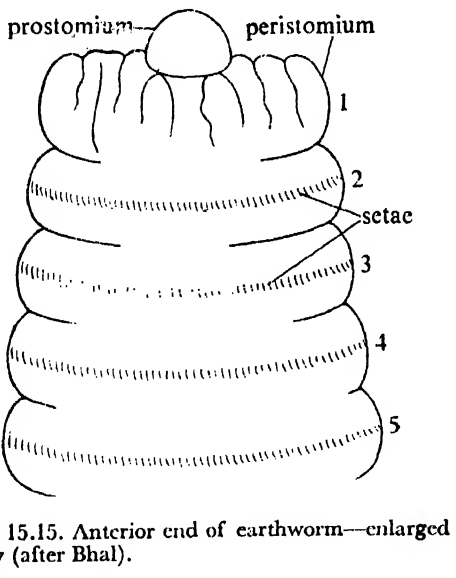


Fig. 15.15. Anterior end of earthworm—enlarged view (after Bhal).

at its posterior end. The apertures in the body are: (*a*) MOUTH—a crescent-shaped aperture situated ventrally in the peristomium; (*b*) ANUS—a round aperture situated at the posterior end of the last segment; (*c*) FEMALE GENITAL APERTURE—a single aperture situated on the mid-ventral line of the 14th segment; (*d*) MALE GENITAL APERTURES—paired apertures situated on the ventro-lateral sides of the 18th segment. Each of these male genital apertures is associated with one pair of *genital papillae*, situated above and below the aperture, i.e. on 17th and 19th segments; (*e*) SPERMATHECAL APERTURES—four pairs, situated on ventro-lateral sides of intersegmental grooves between segments 5/6, 6/7, 7/8, 8/9; (*f*) DORSAL PORES—these apertures are present in the mid-dorsal line of the intersegmental grooves of the segments, between thirteenth to last but one; (*g*) NEPHRIDIOPORES—are numerous and open on the ventral surface of the body. They are present in all segments excepting the first six and the last one.

Seta. Locomotor organs in case of earthworms are called *setae*. Each seta is an elongated more or less 'S'-shaped rod composed of chitin, hardened and strengthened by the addition of sclerotised protein and is embedded in an epidermal pit called *setigerous sac* or *setal sac*. The distal end of the seta is pointed but the proximal end is blunt. The middle of the seta is swollen and is called the *nodulus*. They are about 0·24 mm in length and 0·03 mm in breadth. The number of setae in different segments varies considerably. Usually they are numerous in each segment and are disposed in the form of a ring round each segment (Fig. 15.16A). About two-third of the seta remains inside body wall and one-third of it projects out (Fig. 15.16B). The inner part is attached to muscles responsible for moving the setae. Setae are present in all segments excepting the first, last and the clitellar segments. Setae are organs of locomotion on ground and act as attaching structures in burrows.

Body wall. The body wall is covered externally by a thin non-cellular *cuticle* composed of parallel layers of collagenous fibres and is perforated by numerous pores through which open the epidermal glands. Histologically, it consists of two layers separated by an intervening layer. The cuticle is secreted by the supporting cells of the underneath epidermis. Below the cuticle is the single-layered *epidermis* (Fig. 15.16B). The cells that are found in the epidermis are: (*a*) GLAND CELLS OR GOBLET CELLS—These are mucus-secreting cells which keep the skin moist and slimy. Gland cells are of two types—*mucous cells* and *albumen cells*; (*b*) SUPPORTING CELLS—These are tall and large cells outnumbering the other cells; (*c*) BASAL CELLS—Cells remain packed between gland cells and supporting cells; (*d*) SENSORY CELLS—Occur in

groups and act as receptor organs. All epidermal cells are of columnar type. Below the epidermis there is *circular* muscle layer forming a thin continuous sheet. Circular muscle layer is followed by *longitudinal muscle* layer running in parallel bundles. The bundles are separated from each other by a thin septum of connective tissue. The innermost layer of the body wall is formed by COELOMIC EPITHELIUM which is a thin membrane of single layer of cells.

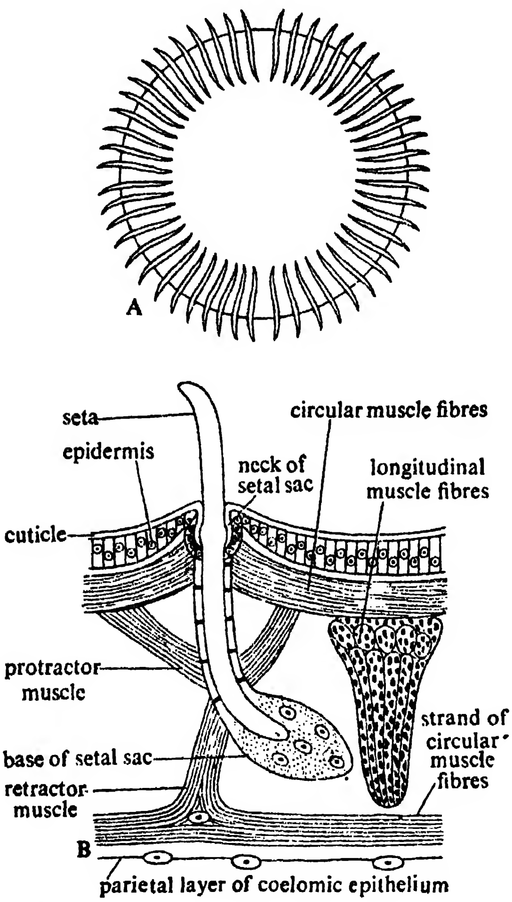


Fig. 15.16. A. Geometric disposition of setae in *Pheretima* (after Bhal). B. Diagrammatic view of a portion of the body wall of earthworm (Transverse section, after Bhal).

Coelom. The coelom or body cavity is extensive. But it is not continuous and is divided into a number of compartments by transverse partitions running between the body wall and the alimentary canal. These partitions or *septa* are vertical in disposition and are formed by double layers of peritoneum and numerous interlacing bundles of muscle fibres. The communications between the various coelomic compartments are provided by sphincter apertures situated just dorsal to nerve cord in each septum. In normal condition the sphincter muscles remain contracted keeping each coelomic compartment separated from each other. The coelom opens to the exterior by dorsal pores and nephridiopores. The number of coelomic compartments corresponds to the number of external segments. However, in the first four segments, the coelom is continuous as the septa are lacking there.

The coelomic compartments remain filled with *coelomic fluid.* The coelomic fluid is milk-white in colour and consists of *plasma* and four types of *nucleated corpuscles* (Fig. 15.17). The corpuscles are: (*a*) *Phagocytes*—these cells are saucer-shaped granular, large and are most numerous;

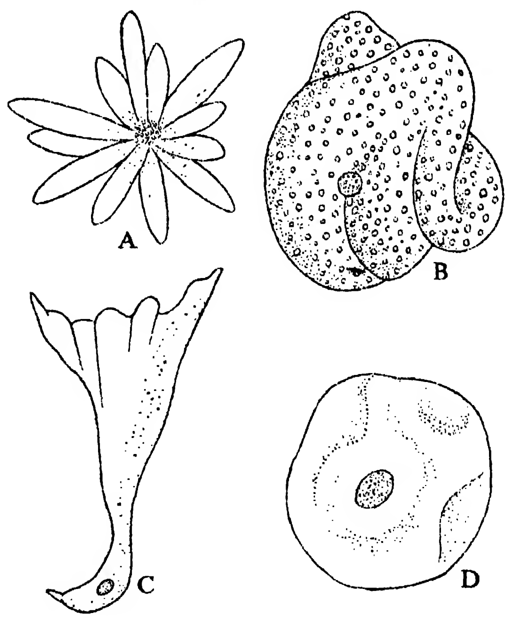


Fig. 15.17. Ceolomic fluid cells of earthworm (after Bhal)—A. Chloragogen cell. B. Phagocyte. C. Mucocyte. D. Circular nucleated cell.

(*b*) *Circular nucleated cell*—these cells are non-granular; (*c*) *Mucocytes*—these are flat, circular and slender cells with fan-like process; (*d*) *Chloragogen cell*—these small but numerous cells have bulgings. When stained with iodine solution, they become yellow.

Locomotion. The locomotion of earthworm is of interest since it gives an opportunity to study the results of

co-ordinated movements in an animal built on a metameric plan. When an earthworm starts to crawl, the first few segments become thinner and longer. This is caused by contraction of circular muscles and relaxation of longitudinal muscles of that region, the opposing sets of muscles are antagonised by an increase in the pressure of the coelomic fluid. The thinning and elongation of the body gradually spread to more posterior segments. At this stage the setae of the anterior region are protruded to grip on the substratum. The longitudinal muscles of the anterior region then contract so that the body at that region becomes shorter and stouter and more hinder regions are pulled forward. The septa also play an important role as they act as water-tight partitions which relay pressure changes from one segment to the next by bulging.

Digestive system. The alimentary canal is a straight tube running from the anterior mouth to the posterior anus (Fig. 15.18). The *mouth* is a crescent-shaped aperture situated ventrally on the peristomium. Mouth opens into a short, thin-walled *buccal cavity*. The outer wall of the buccal cavity leads into the *pharynx* lying in segments 3rd and 4th. The pharynx is pear-shaped and its walls are thick and muscular. The dorsal wall of the pharynx is lobulated and richly vascular. This lobulated part is called *pharyngeal bulb*. The pharynx is followed by *oesophagus* extending up to 8th segment. The part of the oesophagus lying in the 8th segment has become modified to form an oval structure called *gizzard*. The gizzard is thick-walled, muscular and its inner lining epithelium bears a distinct cuticle (Fig. 15.19A). The food particles are ground against the cuticle by muscular efforts and become finer. The part of the alimentary canal lying between segments 9 to 14 is called *stomach*. The wall of the stomach is highly glandular and vascular. Both the ends of the stomach are provided with sphincter muscles. The alimentary canal behind the stomach is wide, thin-walled and continues as *intestine* up to the anus in the last segment. A pair of short and conical *intestinal caeca* is situated at the 26th segment. The dorsal wall of the intestine between 26th and 95th segment is infolded to form the *typhlosole* so that in cross-section this part of the intestine

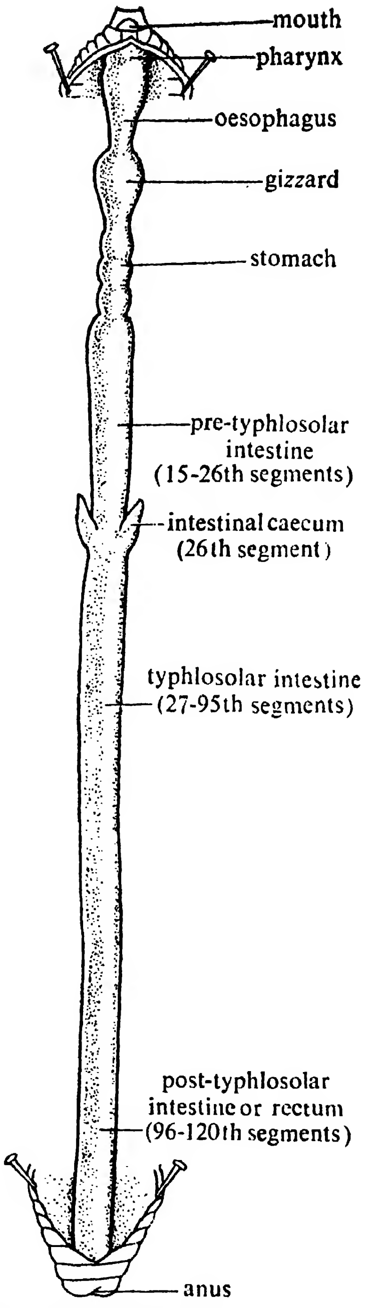


Fig. 15.18. Alimentary canal of earthworm.

appears to be 'U'-shaped (Fig. 15.19B). On the basis of the position of the typhlosole the intestine may be divided into pre-typhlosolar region (segments 15th—26th),

typhlosolar region (segments 26th—95th) and post-typhlosolar region (96th to last). The role of the typhlosole is to increase the surface of absorption. The outer wall of the intestine appears yellowish in colour because of the presence of chloragogen cells which line the intestine.

the leaves are taken in, they are moistened by mucus secreted from the pharyngeal bulb. The food is then forced to the oesophagus by peristalsis. In the oesophagus, enzymes are added. The food then reaches the gizzard whose cuticle renders the food particles finer by grinding. From the

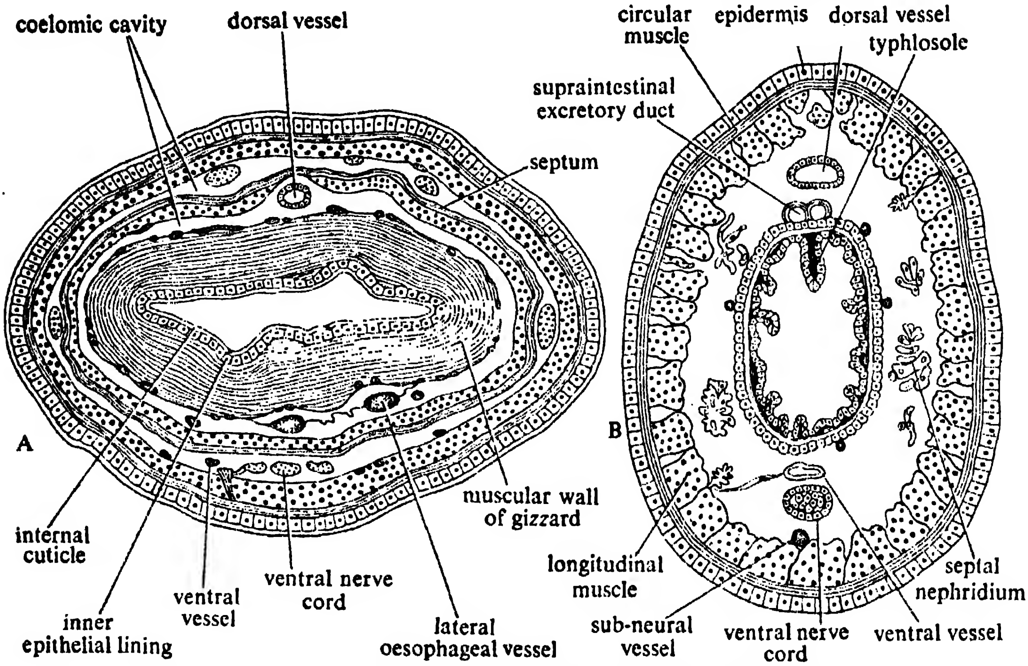


Fig. 15.19. Transverse section of earthworm—A. Passing through gizzard. B. Passing through intestine (after Bhal).

Histology of the gut wall. The outermost layer of the gut wall is made up of tall and narrow cells which are derived from *peritoneal epithelium*. This layer often remains covered by chloragogen cells, laden with yellow pigments. These yellow cells are believed to be excretory in function. Some workers believe that these cells, in addition to their excretory function, take up the role of digestive glands.

The peritoneal epithelium is followed by *longitudinal muscle fibres* and *circular muscle fibres*. The internal epithelium is formed of *glandular* and *ciliated cells*.

Feeding and digestion. During burrowing earthworm swallows soil rich in organic particles, seeds, decaying leaves, ova and larvae of small animals. At night they come out of their holes to feed on leaves and other vegetable matters. The leaves are seized by the pointed end of the mouth and held against the mouth by suction exerted by the pharynx. Before gizzard the food enters into the stomach for digestion and then to intestine for absorption. Insoluble remains of food together with soil that has been ingested are pushed out through anus.

Respiratory system. Definite respiratory organs in earthworm are absent but gaseous exchange for respiration takes place mainly through the skin which is richly supplied with blood vessels and is kept moist by the secretion of epidermal gland cells and by coelomic fluid escaping through the dorsal pores. Carbon dioxide is also carried by blood to the skin from where it is eliminated.

Circulatory system. The blood has the same composition as in Nereis, i.e. it is made up of *plasma* having haemoglobin in dissolved state and colourless nucleated *corpuscles* suspended in plasma. The blood is red in colour.

In the body of the earthworm there is an elaborate circulatory system formed by

closed tubes or blood vessels. The arrangement of the vessels is very complicated. The general plan is that longitudinally running vessels act as collecting or distributing vessels and these are connected with one another by transverse vessels in the individual segments. There are four pairs of such transverse vessels which are called '*hearts*'. As these are not like true hearts of the vertebrates it is better to call them *pseudohearts*. The arrangements of blood vessels in the first thirteen segments and in the rest of the body offer points of contrast. So for the sake of convenience they are described separately.

Blood vessels in the intestinal region or segments beyond thirteenth. In this region of the body three large main vessels run longitudinally and parallel to each other (Fig. 15.20B).

(*a*) **Dorsal vessel.** This large vessel runs in the mid-dorsal line of the body and just above the alimentary canal. The

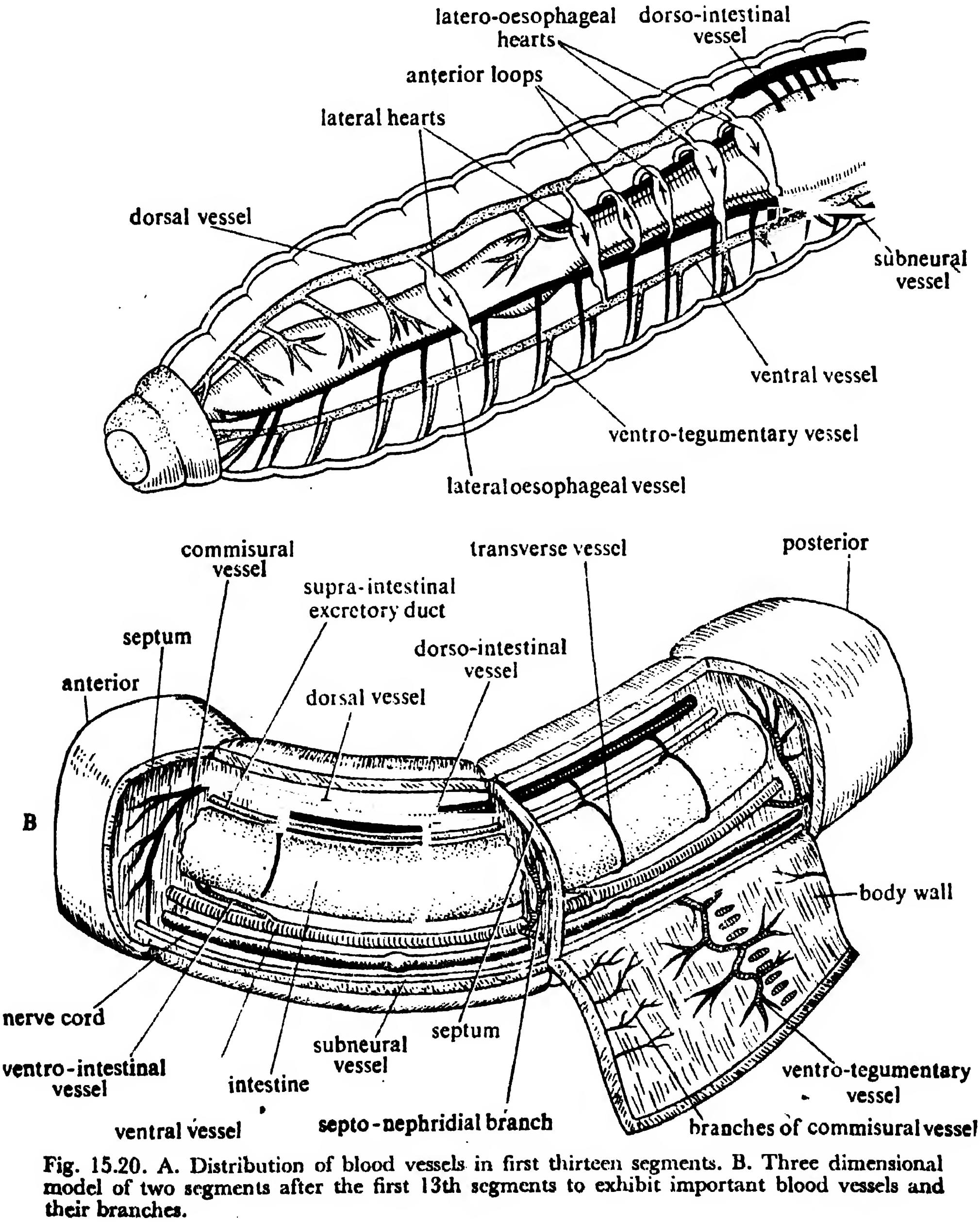


Fig. 15.20. A. Distribution of blood vessels in first thirteen segments. B. Three dimensional model of two segments after the first 13th segments to exhibit important blood vessels and their branches.

direction of movement of blood in this vessel is from behind forward. The dorsal vessel is a collecting vessel and in each segment it receives (*i*) a pair of *dorso-intestinal* vessels in each side bringing blood from the intestine and (*ii*) a *commissural vessel* running along the posterior border of each septum and joined ventrally to the subneural vessel. The vessel collects blood from skin and nephridia. The walls of the dorsal vessel is muscular and its lumen is provided with valves. In each segment there is a pair of valves directed forward and inward to prevent back flow of blood.

(*b*) **Ventral vessel.** This is a long vessel which runs in the mid-ventral line beneath the intestine. The direction of flow of blood is from anterior or posterior. It serves as a distributing vessel and distributes blood through (*i*) a pair of *ventro-tegumentary branches* one on each side of each septum. Each branch pierces the septum behind it and runs upward to supply blood to inner body wall and integumentary nephridium. Each ventro-tegumentary branch gives a septo-nephridial branch which runs on the anterior face of the septum supplying blood to septal nephridia, (*ii*) a median *ventro-intestinal* is given off dorsally from the ventral vessel. It supplies blood to the floor of the intestine. Valves in the lumen of ventral vessel are absent.

(*c*) **Subneural vessel.** It is a long and slender vessel running along the mid-ventral line beneath the nerve cord. The flow of blood is from front to backward. It is a collecting vessel. It collects blood in each segment by a pair of ventral branches, which collect blood from ventral skin. The subneural vessel is linked to dorsal vessel by a pair of commissural vessels in each segment. Extending from the posterior end to the 14th segment, it bifurcates into two to form the *lateral oesophageal vessels*.

Blood plexus of the intestine. The intestinal walls are traversed by a close network of capillaries. The capillary networks are constituted by an internal network between circular muscle layer and internal epithelial lining of intestine and an external network on the outer surface of the intestine.

Commissural, integumentary and nephridial vessels. The commissural vessel gives off from its ventro-lateral side a septo-intestinal branch to the internal plexus. The branches of the integumentary vessels from body wall and nephridial vessels open into the internal plexus.

Blood vascular system in the first thirteen segments. The first thirteen segments have the following vessels (Fig. 15.20A).

(*a*) Dorsal vessel. It becomes the distributing vessel at this region and extends up to the cerebral ganglion. It gives off branches which supply the anterior regions of the body. It sends back blood to the ventral vessel through the 'hearts'.

(*b*) **Supra-oesophageal vessel.** A very short vessel extending between segments 9th and 13th. It is a collecting vessel and collects blood from gizzard and stomach.

(*c*) **Lateral oesophageal vessel.** These vessels have been formed by the bifurcation of the subneutral vessel at the 14th segment. These are collecting vessels and continue anteriorly along the lateral sides of the oesophagus. Through a pair of branches in each segment they collect blood from lateral regions of gut, body wall, septum and seminal vesicle.

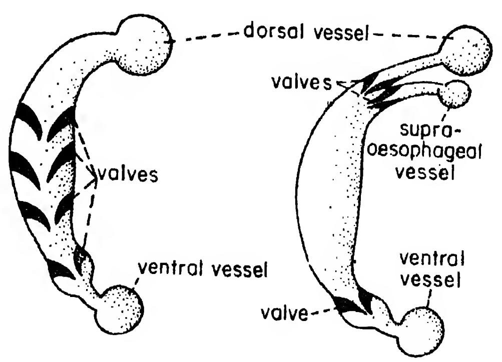


Fig. 15.21. Heart in earthworm (diagrammatic representation) I—Lateral heart, II—Latero-oesophageal heart.

(*d*) **Ventral vessel.** It extends anteriorly up to the 2nd segment and is a supplying vessel. It supplies blood to ventral body wall, septal nephridia and reproductive organs. It gives a pair of ventrotegumentary vessels in each segment.

Hearts and anterior loops. The dorsal and ventral vessels are connected to each other in segments 7th, 9th, 12th and 13th by means of paired pulsatile structures

called 'hearts' (Fig. 15.21). The posterior two pairs situated in 12th and 13th segments are called *latero-oesophageal hearts* because they communicate dorsally both with dorsal and supra-oesophageal vessels while the anterior pairs situated in the 7th and 9th segments are called *lateral hearts* because they communicate directly the ventral vessel to the dorsal vessel. Besides these, there are two pairs of non-pulsatile *loops* situated in 10th and 11th segments. These loops connect the supra-oesophageal to the lateral oesophageals.

Ring vessels. The wall of the stomach between segments 10th and 13th bear dozens of circular vessels in each segment. Blood from lateral oesophageals to the supra-oesophageal is carried by these vessels.

Mechanism of blood circulation. The movement of blood through the different vessels is carried on by peristaltic contractions (Fig. 15.22). There are a pair of ring collected by the paired branches of sub-neural vessel and by the capillaries of the commissurals, which in their turns open to the dorsal vessel. Moreover, the dorsal vessel also receive the dorso-intestinals from the intestine in the intestinal region where it acts as a collecting vessel. In the first thirteen segments the dorsal vessel becomes a distributing vessel and pours blood in the ventral vessel through hearts. The ventral vessel does not distribute blood.

Blood-forming glands. Behind the pharyngeal mass in segment 4th and behind it in 5th and 6th segments, there exists an aggregate of spherical follicles called *blood glands*. Each follicle consists of a capsule of syncytial layer of multinucleated protoplasm having in its concavity a loose mass of cells. The blood glands are considered as manufacturers of blood corpuscles and haemoglobin.

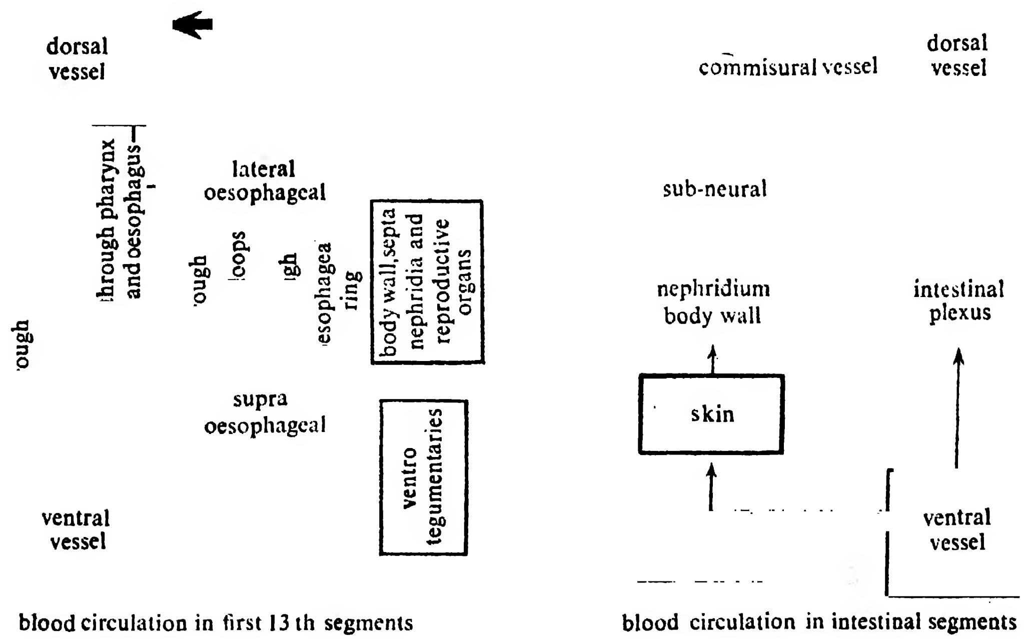


Fig. 15.22. Route of blood flow in earthworm.

valves in front of each septum directing blood forward or backward as the case may be, which prevent back flow. Blood is carried to the skin by the ventro-tegumentary branches from the ventral vessel for aeration. Oxygenated blood is

Excretory system. Excretory organs are the *nephridia*. Nephridia occur in all segments excepting the first three and the last segments. The nephridia are small and coiled tubular structures and occur in huge numbers.

In the body of earthworm three kinds of (Fig. 15.23) nephridia occur—*septal, integumentary* and *pharyngeal*. Structurally, these nephridia show basic similarities, its classification is based on its position in the body. The types of nephridia that occur in earthworm are:

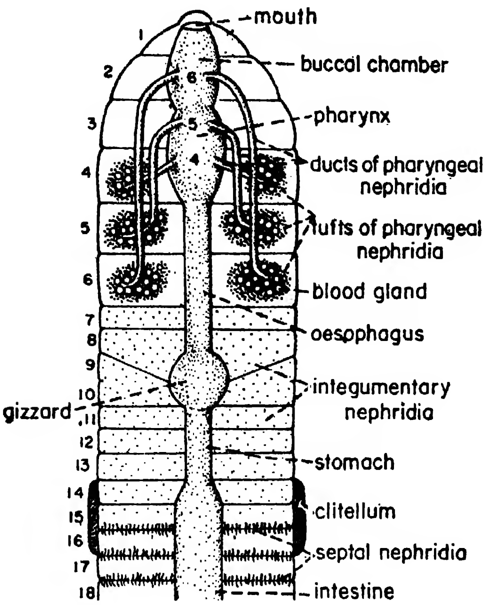


Fig. 15.23. Different types of nephridia in earthworm.

(*a*) **Septal nephridia.** Septal nephridia remain attached to the two faces of the septum. They occur from 15th segment backward. That means in the first fourteen segments they are absent. Each septum bears 40–50 nephridia in average in its anterior and a similar number on its posterior face. Thus in each segment there are about 80–100 nephridia.

Structure of septal nephridium. A typical septal nephridium (Fig. 15.24A) consists of a *main body* formed by a straight

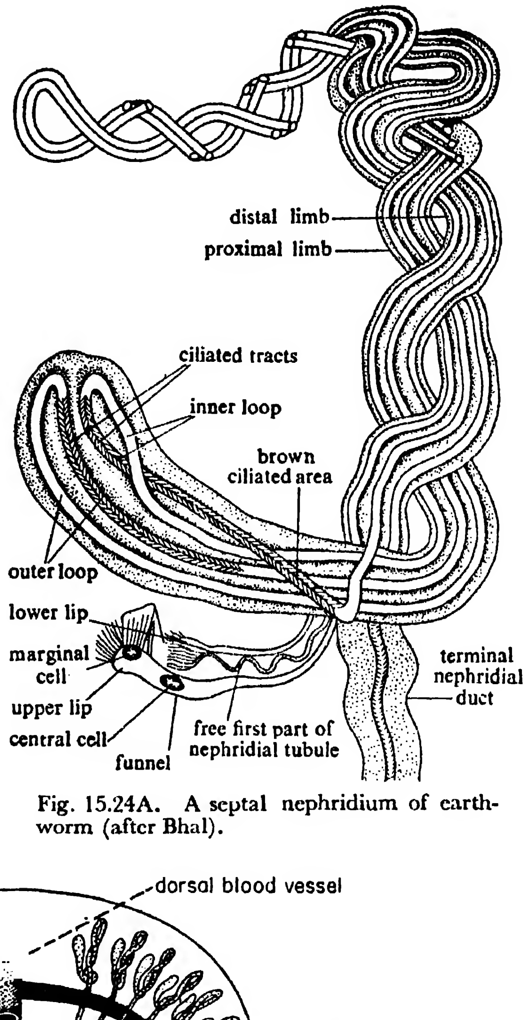


Fig. 15.24A. A septal nephridium of earthworm (after Bhal).

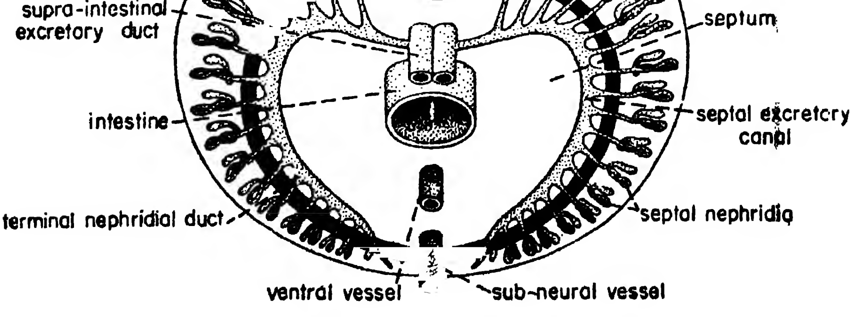


Fig. 15.24B. Showing the relationship between septal nephridial system and intestine in earthworm.

lobe and a long narrow, spirally twisted loop, a funnel-like *nephrostome* connected to the main body by a short *neck* and a *terminal nephridial duct*. All the nephridial structures remain restricted to the same segment.

The nephrostome or funnel is a rounded structure. The mouth of the funnel which communicates with the coelom is provided with a large upper lip and a small lower lip. The lips are ciliated. A narrow ciliated tube runs from the funnel into the body of the nephridium and takes several turns inside it.

The main body of the nephridium is made up of a main lobe and a spirally twisted loop. The loop is twice as long as the main lobe and consists of a *proximal* limb and a *distal* limb twisted round each other. The straight lobe is continued as the distal limb of the twisted loop and the proximal limb receives the ciliated tubule from the nephrostome and also it gives off the terminal duct which opens at the nephridiopore. The straight lobe bears four parallel tubules, the proximal and distal ones bear three tubules each and in the apical part there are two tubules.

Terminal ducts of the septal nephridium open into a *septal excretory canal* which runs parallel and internal to commissural vessels.

There are a pair of septal excretory canals one on each side of the septum. The two septal excretory canals open into a pair of *supra-intestinal excretory ducts* which run on the mid-dorsal line side by side from 15th segment to the posterior end. The supra-intestinal excretory ducts open into the lumen of the intestine by single and small ducts at the level of each intersegmental septum.

(*b*) **Integumentary nephridia.** They are smaller in size than the septal nephridia. These 'V'-shaped structures occur on the inner surface of the integument in all segments excepting the first two. They number 200–250 in each segment but in the 14th, 15th and 16th segments the number of nephridia is much more. Structurally they resemble septal nephridia but lack the nephrostome. They open independently to the outside by nephridiopores on the outer surface of the body wall.

(*c*) **Pharyngeal nephridia.** They are as large as the septal nephridia and occur in the form of three pairs of bunches or tufts in the 4th, 5th and 6th segments and on either side of pharynx and oesophagus. Nephrostomes are also absent in the pharyngeal nephridia. In each bunch the terminal ducts of the nephridia join together to form a slender duct. The slender ducts again unite in each segment and form a thick-walled duct which opens into the alimentary tube. Thus there are three pairs of ducts, one pair each in the 4th, 5th and 6th segments. Some workers maintain that the pharyngeal nephridia have digestive function or, in other words, they aid in digestion and hence they are sometimes referred to as 'peptic nephridia'.

The sepal and pharyngeal nephridia open into the alimentary canal and are called *enteronephric* while the integumentary nephridia open to the outside directly and are called *exonephric*. The enteronephric system helps in the conservation of water in the body because water present in the excretory product is again reabsorbed in the intestine.

Some of the nitrogenous excretory substances like *guanin* are extracted from the blood stream by chloragogen cells. These cells collect and store excretory products and on becoming heavily laden with excretory materials, they pinch off into the coelomic fluid from where they are eliminated through dorsal pores or by nephridiopores.

Nervous system

The nervous system (Fig. 15.25) comprises of a *central nervous system* from which *peripheral nerves* are given to the different parts of the body and the *receptor organs*.

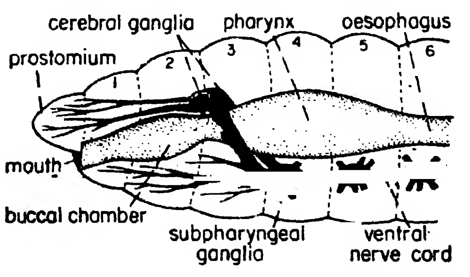


Fig. 15.25. Nervous system of earthworm.

Central nervous system. It consists of a pair of closely packed SUPRAPHARYNGEAL GANGLIA OR CEREBRAL GANGLIA forming the brain and situated in the third segment of the body above the pharynx.

From the brain nerves are given off to the prostomium and walls of the buccal chamber. Two loops called CIRCUM PHARYNGEAL CONNECTIVES arise, one from each ganglion of the brain. They encircle the pharynx and meet with a pair of SUB-PHARYNGEAL GANGLIA lying below the pharynx and in the anterior part of the fourth segment. The connectives give off nerves to the first segment of the body and to the buccal chamber and the sub-pharyngeal ganglia give branches to supply the second, third and fourth segments.

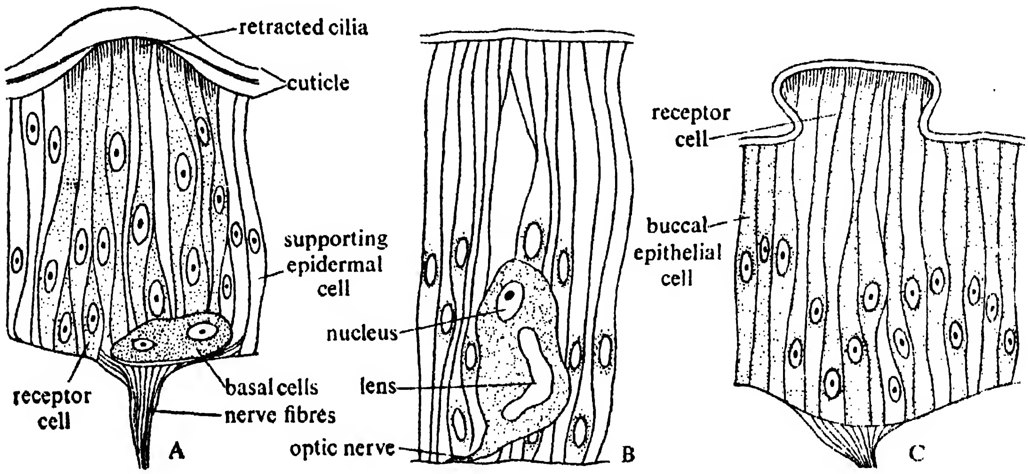


Fig. 15.26. Receptor organs in earthworm. A. Epidermal receptor. B. Photoreceptor (in *Lumbricus*) C. Buccal receptor.

A **ventral nerve cord** extends from the subpharyngeal ganglia to the last segment of the body and runs along the mid-ventral line. The nerve cord, though appears single, is in reality made up of two cords. Behind the fourth segment the cord presents a swelling in each segment. Each swelling is formed by fusion of paired ganglia. From each of these ganglia, three pairs of peripheral nerves are given to the body wall and viscera. These nerves contain both *afferent* and *efferent fibres*.

Receptor organs. The structures which receive stimuli and convey the same to the central nervous system are called *receptors*. The receptors found in the body of earthworm are described below:

(*a*) EPIDERMAL RECEPTORS. These receptors are placed in the epidermis as groups of long slender receptor cells (Fig. 15.26A) which are tactile in function.

(*b*) PHOTORECEPTORS. Each photoreceptor (Fig. 15.26B) is a single cell with a distinct nucleus and an optic organella. These receptor cells are housed in the epidermis. The cells are numerous at the anterior end of the body. The number gradually decreases posteriorly. The last segment may even contain one such cell. The receptor cells are absent on the ventral surface.

(*c*) **Buccal receptors.** Groups of cells are placed in the buccal cavity in large numbers. These receptors are concerned with chemical stimuli and serve in smelling and tasting food particles. (Fig. 15.26C).

Reproductive system

Earthworm is monoecious or hermaphrodite, i.e. male and female reproductive structures develop in the same individual.

Male reproductive system. Two pairs of *testis sacs* are located beneath the oesophagus in 10th and 11th segments (Fig. 15.27A). There are two pairs of *seminal vesicles* placed laterally in the 11th and 12th segments. The testis sacs are communicated to the vesicles of their own sides. The testis sac situated on the right side of 10th segment communicates to the vesicle of the right side in the 11th segment and so on. In each testis sac, the reproductive organ, testis remains attached on the inner surface of the anterior end of the sac. Thus, there are two pairs of testes. The testes are digited structures and each testis is made up of testicular lobules or follicles. Sperm mother cells are discharged in the cavities of the sacs. From there they go to

the seminal vesicles and after maturity again come back to the sacs. Behind each testis there is a *spermiducal funnel*. The funnel leads into a slender duct called *spermiduct* or *vas deferens*. There are four *vasa deferentia*. The two vasa deferentia of each side continue posteriorly from the 12th to 18th segment and enter into the *prostate gland*.

There is a pair of prostate or spermiducal glands extending usually from 17th to 21st segments. Each gland gives out a duct. This duct along with the two vasa deferentia of its own side becomes enclosed in a common muscular sheath and opens through the male genital aperture situated in the 18th segment.

Female reproductive system. The reproductive organs are a pair of *ovaries* attached to the hinder face of the septum lying between 12th and 13th segments (Fig. 15.27B). The ovary is also a digited structure and it contains ova. The ovaries are larger than the testes. Beneath each ovary lies an oviducal or ovarian funnel.

The funnels are ciliated and the two oviducts unite to form a common oviduct which opens to the outside by the female genital aperture situated ventrally on the 14th segment.

There are four pairs of spermathecae in the 6th to 9th segments of the body. Each sac consists of a flask-shaped *ampulla* and a narrow *duct*. The ducts open to the outside through spermathecal pores situated in the segments between 5/6, 6/7, 7/8 and 8/9 segments. The sperms are stored in the spermathecae.

Copulation. Though hermaphrodite, earthworm practices cross-fertilization. Mating occurs in the summer. During mating two individuals come together and oppose each other in a head to tail position. The male genital apertures of one rest on the spermathecal pores of the other. After mutual exchange of sperms the indi-

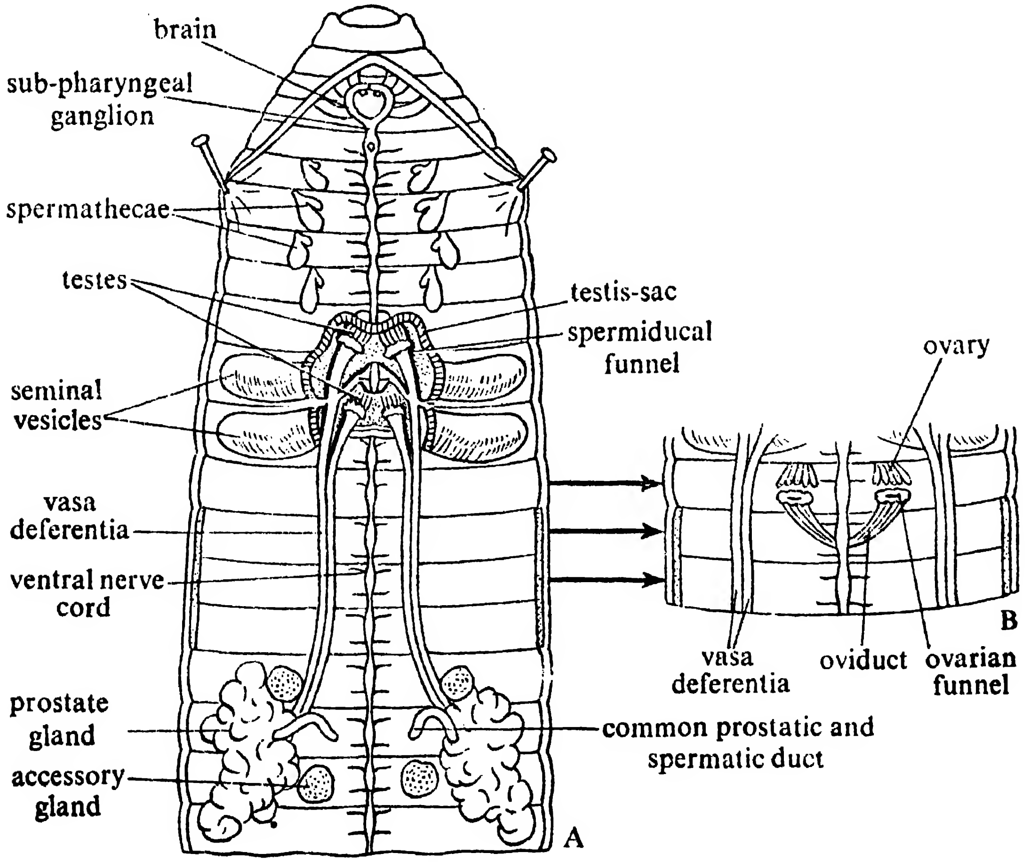


Fig. 15.27. Reproductive and nervous systems of Earthworm. Male (A) and Female (B) reproductive systems are drawn separately. But it must be remembered that both are present in the same individual, the clitellum may be taken as a marker to their relative positions.

viduals separate and sperms remain stored in the spermathecae.

COCOON FORMATION AND DEVELOPMENT. Clitellar glands secrete some substances which are cemented together to form a membranous girdle round the clitellar region. The earthworm now tries to pull itself out of the girdle. When the girdle slips over the oviducal aperture, ova are discharged into it and as it passes over the spermathecal apertures, sperms are also discharged. The animal pulls its body out of this girdle. The two open ends of the girdle due to elasticity become closed and a *cocoon* is formed. Fertilization and development occur inside the cocoon. Generally, one individual comes out of one cocoon. Development is direct and the developing embryo gets nourishment from stored albumen.

EXAMPLE OF THE PHYLUM ANNELIDA—*LEECH*

Habit and Habitat

Several kinds of leeches are found in our country. The type which is discussed here is commonly called cattle leech and its scientific name is *Hirudinaria granulosa*. It is a member of the class Hirudinea. These leeches are seen in swamps, ponds and slow-flowing streams. It is sanguinivorous (lives on blood meal) and ectoparasitic in nature.

External structures

Body is elongated and vermiform (Fig. 15.28). Body appears cylindrical in contracted state and dorso-ventrally flattened in extended condition. A full-grown leech measures 35–40 cm in length. Leeches are brightly coloured. The dorsal surface is olive-green and the ventral surface is orange-yellow or yellow in colour. The dorsal surface also bears stripes of orange or yellow. On the mid-dorsal surface there is a long stripe extending from the first pair of eyes to the anus. This stripe is either uniform or interrupted. On either side of this median stripe there are four discontinuous wavy stripes extending from tip to tip of the body. The stripes, running along the outermost sides of the body, bear *supra-marginal spots* on the 2nd and 5th annuli of each segment. These spots offer keys to taxonomy. The first and second stripes on each side of the middle stripe are irregular and inconspicuous. These stripes have been termed as *inner paramedian*, *outer paramedian*, *intermediate*, and *supra-marginal*. The first annulus of each segment bears a ring of *segmental receptor organs* or *segmental papillae* in the form of small elevations.

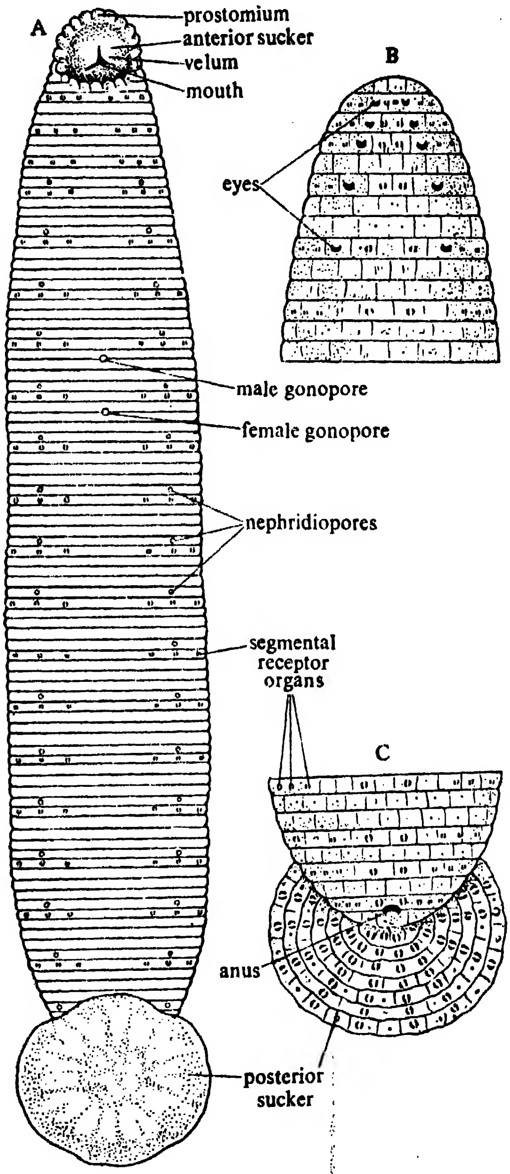


Fig. 15.28. External structures of *Hirudinaria*. A. Ventral view. B. Anterior end (Dorsal view). C. Posterior end (Dorsal view).

Number of segments in the body are fixed and they are thirty-three. These true segments have been divided externally into *annuli* by superficial furrows. Each segment bears three to five such external

furrows. The body may be divided into following regions:

(*a*) **Cephalic or Head region.** It is constituted by five anterior segments (Fig. 15.28 B). The two anteriormost segments (1st and 2nd) are not divided into annuli. The third segment is bi-annulate while both of the fourth and fifth segments are tri-annulate. The cephalic region includes the *anterior sucker* and the *eyes*. There are five pairs of eyes; the first and second pairs are situated on the 1st and 2nd segments. The third, fourth and fifth pairs of eyes are situated on the 1st annulus of 3rd, 4th and 5th segments respectively. The anterior sucker is situated on the ventral surface of the cephalic region. It is cup-shaped, oval in outline and is formed by the fusion of anterior five segments on the ventral surface. At the bottom of the cup-shaped sucker lies the *mouth* which is narrow and tri-radiate. At the tip of the cephalic region and above the first segment is situated the *prostomium* which serves as a sort of upper lip to the mouth and bears glands and sense organs for touch and taste.

(*b*) **Pre-clitellar region.** It is constituted by segments 6th, 7th and 8th. The 6th segment has three annuli while in the other two there are five annuli. All these segments bear a pair of *nephridiopores* on the ventral surface.

(*c*) **Clitellar region.** The 9th, 10th and 11th segments form the clitellar region. The 10th segment bears in its mid-ventral line the male genital aperture while the female genital aperture is situated on the mid-ventral line of the 11th segment. Each segment has a pair of nephridiopores on the ventral surface. Permanent clitellum is lacking in leeches. Clitellum becomes prominent in breeding season.

(*d*) **Middle region.** The eleven segments starting from 12th to 22nd are provided with five annuli and nephridiopores.

(*e*) **Caudal region.** It is made up of segments from 23rd to 26th (Fig. 15.28C). The 23rd segment is with three annuli and others are with two. On the dorsal surface of the 26th segment a median aperture, *anus* is present in the furrow between two annuli. Nephridiopores are absent.

(*f*) **Posterior sucker region.** Constituted by seven segments from 27th to 33rd. None of the segments is annulated and all the segments are indicated by seven circles. Segmental receptors are very prominent on the suckers. The posterior sucker is much larger and more powerful than the anterior one.

Body wall

The outer covering of the body wall is *cuticle* which is a non-cellular, thin and transparent membrane secreted by the epidermis (Fig. 15.29A). It is perforated by

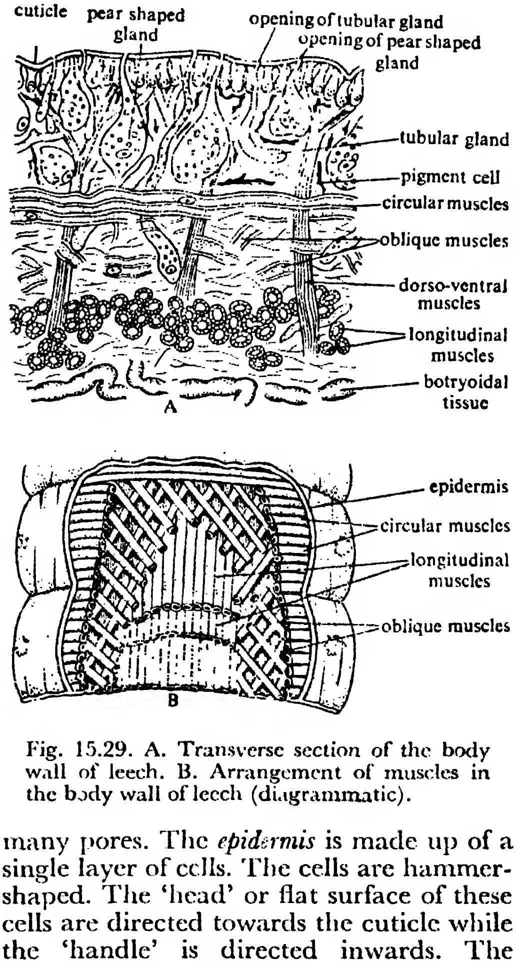


Fig. 15.29. A. Transverse section of the body wall of leech. B. Arrangement of muscles in the body wall of leech (diagrammatic).

many pores. The *epidermis* is made up of a single layer of cells. The cells are hammer-shaped. The 'head' or flat surface of these cells are directed towards the cuticle while the 'handle' is directed inwards. The spaces between the inner ends of the epidermal cells are occupied by fibrous connective tissues containing blood and capillaries. Embedded in the connective tissue are unicellular *epidermal glands*. Groups of cells become modified to form receptor cells. Four types of glands are recognised.

(*a*) **Slime glands**—distributed all over the surface and secrete slime. They may be "pear-shaped" or "tubular" in appearance.

(*b*) **Sucker glands**—situated in masses on anterior and posterior suckers.

(*c*) **Prostomial glands**—These are placed in groups on the prostomium, the secretions form plugs during cocoon formation.

(*d*) **Clitellar glands**—These are present in the clitellar region. The secretory activity of glands increases during breeding season.

The glands open to the outside through the pores on the cuticle. Epidermis is followed by a thick *dermis* which is an assemblage of *fibrous connective tissue* containing short muscle fibres, haemocoelomic sinuses and capillary networks. The *circular* and *longitudinal muscle layers* follow as usual. Besides these, there occur *oblique*, *dorso-ventral*, *radial* and *vertical muscles*. These muscles are arranged either singly or in bundles (Fig. 15.29B). A peculiar type of connective tissue called *botryoidal tissue* occurs between enteric canal and longitudinal layer of muscles. The tissue consists of large and perforated cells arranged end to end so as to constitute minute intra-cellular canals filled with haemocoelomic fluid. The cells are heavily pigmented and appear black in colour.

The detailed histological structure of the body wall is best seen in transverse sections passing through the body (Fig. 15.30). A transverse section from the middle of the body shows above-mentioned structures of the body wall. Besides, in such sections it is seen that the major part of the body space is occupied by the *crop* and its lateral diverticula, the *caeca*. The crop and the diverticula are lined internally by endoderm which is projected towards the lumen of the alimentary canal. The lateral sides are occupied by *nephridia*. Below the nephridia run the *lateral haemocoelomic channels*. Above the crop lies the *dorsal haemocoelomic channel* while below the crop lies the *ventral haemocoelomic channel*. The *ventral nerve cord* passes through the ventral haemocoelomic channel.

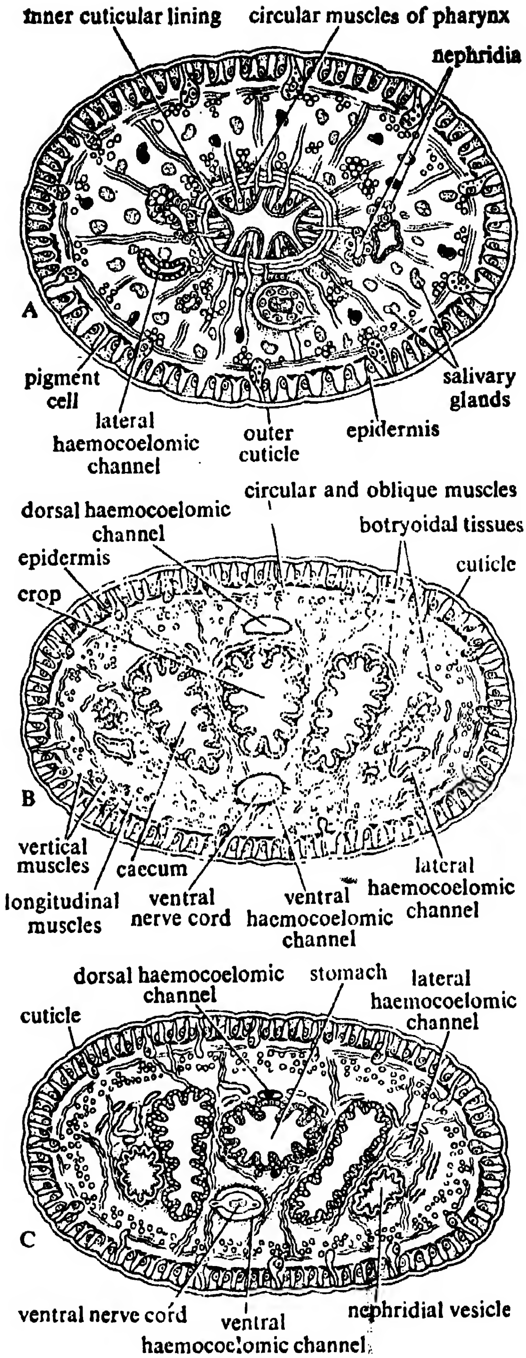


Fig. 15.30. Transverse section of leech. A. Passing through pharynx. Note the cuticular nature of the inner lining, highly-developed musculature and the presence of salivary glands. B. Passing through crop. Note the thin nature of the crop and the diverticula. The inner lining of the crop and the diverticula are projected. C. Passing through stomach. Note the lining membrane is thrown into folds which anastomose and the presence of nephridial vesicles.

Coelom

An extensive and spacious perivisceral coelom is absent in leeches. The coelom is greatly reduced by the development of connective tissue between the alimentary tube and the body wall. The coelom becomes restricted to four longitudinal

channels, two of which are lateral, one dorsal and the remaining one is ventral in position. These channels contain coelomic fluid which is red in colour with haemoglobin and corpuscles. So the coelomic fluid is better called *haemocoelomic fluid* and the channels, as the *haemocoel*. True coelom is represented by spaces enclosing the gonads and reproductive ducts.

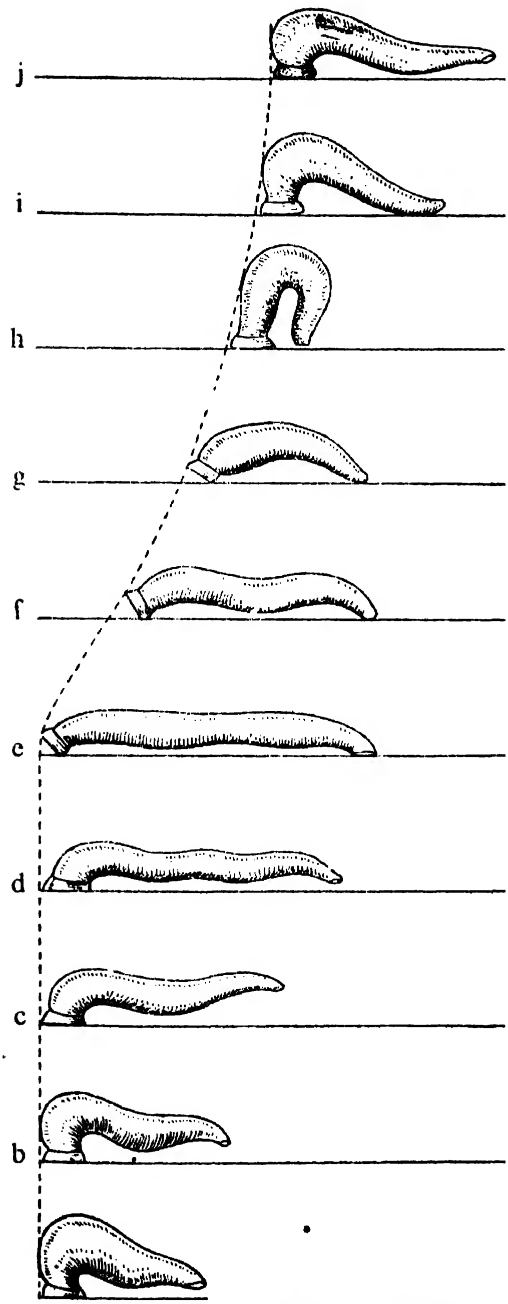


Fig. 15.31. Movement of leech on a substratum.

Locomotion

The leeches can move about from place to place by (*a*) *swimming* and (*b*) *crawling* (Fig. 15.31).

(*a*) **Swimming.** Leeches swim about elegantly in water by snake-like lateral undulations of the body. Bi-lateral waves occur by the contraction of dorso-ventral muscles and relaxation of longitudinal muscles.

(*b*) **Crawling.** Leeches crawl on substratum under water as well as on land by looping. The suckers play their part alternately as adhesive organs. Actual locomotion is effected by alternating changes in the length of the body.

During crawling, the posterior sucker first gets attached to the substratum. This produces a wave of excitation and contraction of the circular muscles and simultaneous relaxation of longitudinal muscles. As a result, great extension of the body length occurs. The animal now fixes the forwarding anterior sucker on the substratum. Now contraction of longitudinal muscles and relaxation of circular muscle occur and the posterior sucker is released from the substratum. The contracting longitudinal muscles drag the posterior sucker forward and the body assumes the shape of a loop or inverted 'U'. The posterior sucker is now fixed in the new position and the animal moves forward by the repetition of the process.

Digestive system

It includes a long *alimentary canal* and digestive glands in the form of *salivary glands* (Fig. 15.32). The alimentary canal starts from *mouth*. Mouth is a tri-radiate aperture situated in the middle of the anterior sucker and leads to a very small *buccal chamber*. The walls of the buccal chamber bear three *jaws* one of which is dorso-median in position and the other two are ventro lateral. The jaws are laterally compressed muscular cushions having chitinous coverings. The chitinous covering is produced into rows of teeth. The jaws can be operated by muscles for backward and forward movements. Both sides of a jaw are provided with *papillae* which bear the openings of the salivary glands. The buccal chamber leads to the *pharynx* which extends from the 5th to the 8th segments. The entire space between

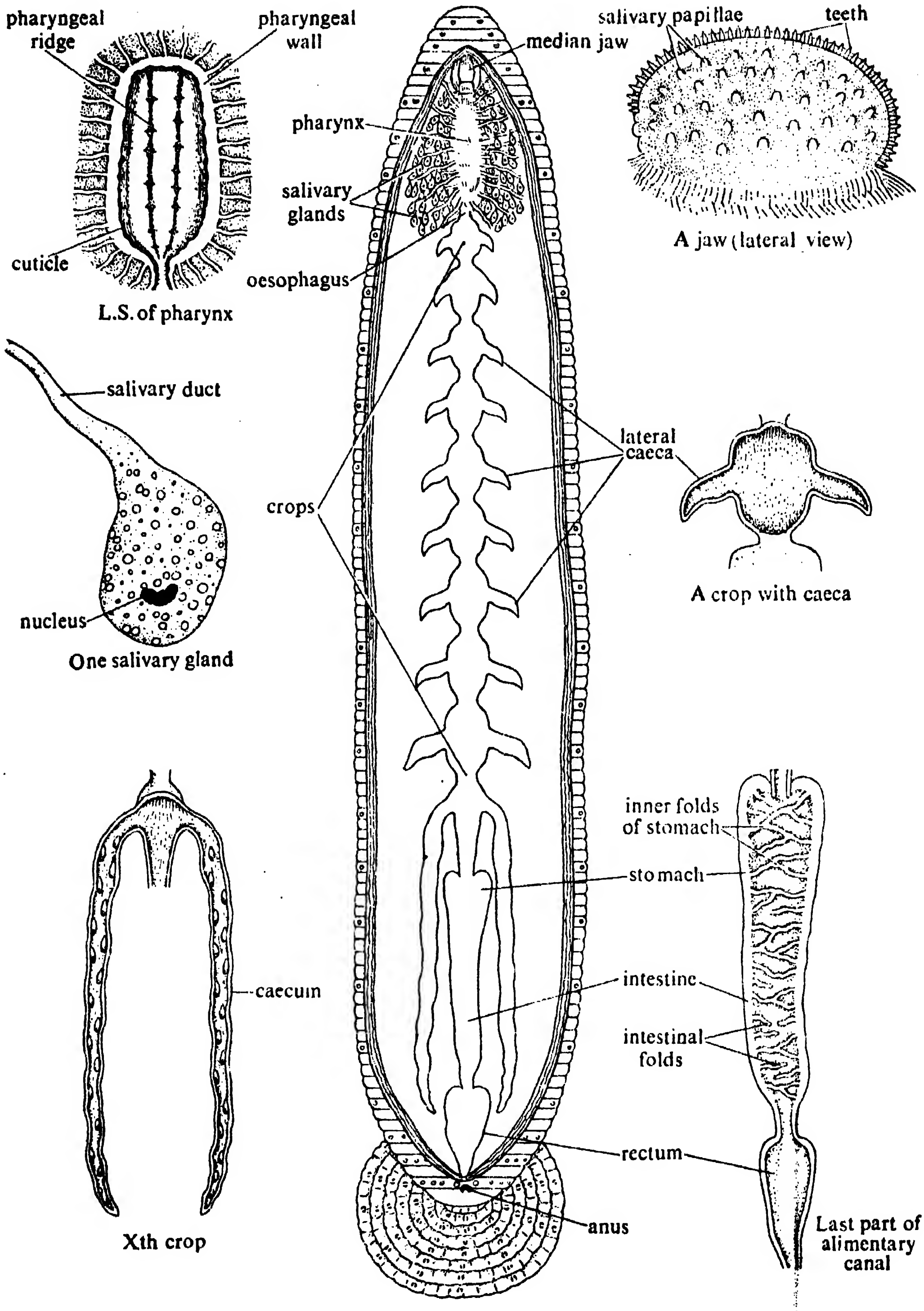


Fig. 15.32. Alimentary system of leech and enlarged view of some of its structures.

pharyngeal wall and body wall is packed with numerous *salivary glands*. The glands are unicellular and open in the papillae by the side of the jaws through ducts. The secretion of the glands prevents the coagulation of blood of the prey during feeding. Radial muscles run between the walls of the pharynx and body wall which operate

to dilate the pharynx and accelerate suction. The pharynx opens into the largest part of the alimentary canal—the crop through a small *oesophagus*. The crop extends from 9th to 18th segments. It is represented by ten chambers arranged metamerically one in each segment. Each chamber opens behind into the succeeding chamber by a round aperture controlled by sphincter. A pair of blind pockets or *caeca* project out laterally from each chamber. The caeca increase in size from before backward. The first pair are the smallest and the last pair are the largest. The last pair of caeca extend as far as 22nd segment. The crop opens into the stomach which is small, tapering and restricted to the 19th segment. The walls of the stomach are produced internally into transverse folds. The stomach continues as *intestine* occupying 20th to 22nd segments. It is a narrow and straight tube and its internal wall bears longitudinal and transverse folds to increase the surface of absorption. The intestine narrows down at the posterior end and enters into the *rectum*. It extends from 22nd to 26th segments. It is thin-walled and it opens to the outside through *anus* which is placed on the dorsal surface of the 26th segment.

Feeding and digestion. Leech is an ectoparasite animal and lives on the blood of vertebrates. A crop full of blood may weigh about 300 gms and is digested and absorbed in several months. A leech gets attached to the body of its prey by the posterior sucker. The cup-shaped anterior sucker is then suitably placed to the soft site on the host skin. The jaws are protruded and their serrated margins then play on the skin of the prey by the action of muscles.

Ultimately a tri-radiate wound is made and blood comes out. This blood is sucked into the pharynx by alternate contraction and expansion of pharyngeal muscles. The secretion of the salivary glands contains an anti-coagulating agent, *hirudin*, which prevents coagulation of blood and thus a continuous flow is maintained. Blood passes into the crop and caeca and is stored there. The stored blood inside the crop becomes transformed into a jelly-like mass by the process of haemolysis.

A drop or two of the blood enter into the stomach from the 10th crop and the flow is controlled by sphincter. The blood is digested here and changed into a green mass. Proteolytic enzymes secreted by the stomach help in digestion. The digested food is absorbed in the intestine and the residue is thrown out as black mass through the anus.

Respiratory system

As in earthworm, the skin serves as respiratory organ in leeches. The skin is richly supplied with haemocoelomic vessels and being permeable, the carbon dioxide of the haemocoelomic fluid in the capillaries is exchanged for oxygen dissolved in water. In some leeches as *Branchellion*, lateral outgrowths of the body wall serve as gills for respiration.

Circulatory system

A closed blood-vascular system like that of earthworm is absent in leeches. The blood vessels are represented by coelomic channels, filled with blood-like fluid. These channels form the haemocoelomic system. The coelomic fluid contains haemoglobin. Colourless corpuscles are circulate through these channels.

The haemocoelomic system consists of (1) four *longitudinal channels* (Fig. 15.33),

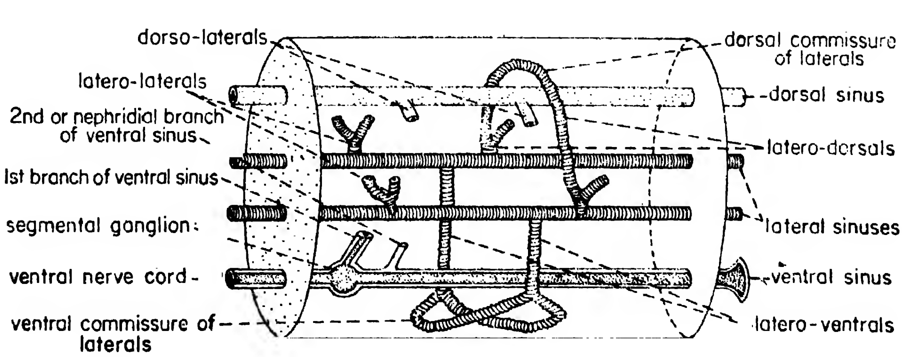


Fig. 15.33. Diagrammatic representation of haemocoelomic system in a segment of leech.

two of which run *laterally*, one on each side, one runs along the *mid-dorsal line* and the other along the *mid-ventral line;* (2) elaborate branches arise from these channels and (3) a large number of *spaces*, some of which are coelomic, while the others are of unknown nature. The four channels are in direct communication to each other at the posterior part of the body.

DIFFERENT LONGITUDINAL CHANNELS

(*i*) **Dorsal channel.** It runs along the mid-dorsal line beneath the body wall and remains firmly attached to the gut. The girth of the channel is more or less uniform. In each segment the dorsal channel gives two pairs of *dorso-lateral* branches.

The dorso-lateral branches arise from the ventral surface of the dorsal channel and run to the dorsal and dorso-lateral sides of body where they form *capillary plexus*. The dorsal channel gives a large number of small *dorso-intestinal branches* to the alimentary canal.

At the 6th segment the dorsal channel breaks up and forms a network of capillaries in the anterior five segments. At the 22nd segment the dorsal channel becomes bifurcated. These branches pass downward round the rectum to enter into the posterior dilatation of the ventral channel. Thus a direct communication between the dorsal and ventral channel is established.

The dorsal channel and its branches are devoid of muscular walls and valves. The flow of fluid is from posterior to anterior end.

(*ii*) **Ventral channel.** It runs beneath the alimentary canal and encloses the ventral nerve cord. Anteriorly, it encloses the cerebral ganglia, peri-pharyngeal nerve ring and the subpharyngeal ganglia. Posteriorly, it encloses the terminal ganglia. The ventral channel extends from anterior to posterior and is larger in diameter than the dorsal channel.

In each segment, the ventral channel gives a pair of branches from the level of each ganglion. Each branch bifurcates into two forming a *ventral branch* which forms a capillary network on the ventro-lateral wall and an *antero-dorsal branch* which runs vertically upward and forms dorso-lateral capillary network on the skin.

In 6th to 22nd segments, the ventral channel gives in each segment a pair of *nephridial branches*. The nephridial branches arise from ventral channel behind the nerve ganglion in each segment and run outwards. They form saccules called *peri-nephrostomial ampullae* around each testis sac and give off minute branches to nephridium and ultimately break up to form capillaries on the lateral body wall.

The ventral channel and its branches are thin-walled and without valves.

The direction of movement of haemocoelomic fluid is from the anterior to the posterior end.

(*iii*) **Lateral channel.** The two lateral channels which have muscular walls run symmetrically one on each side of the alimentary tube. The diameter of the channels is wider at the posterior third of the body.

Each lateral channel gives off in each segment a single *latero-ventral branch* which soon bifurcates to form anterior and

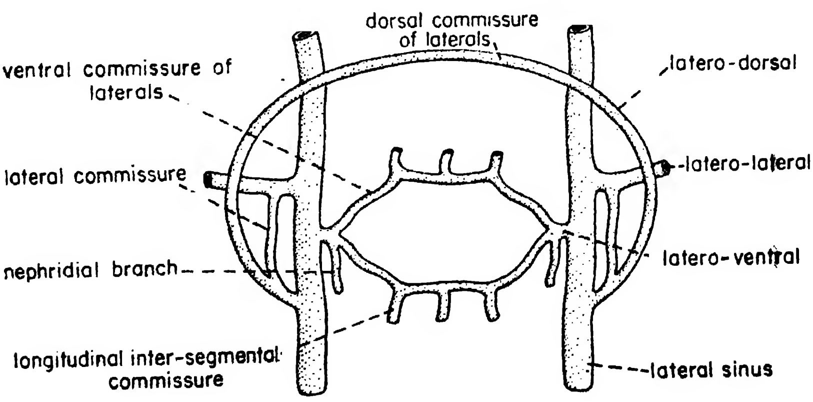


Fig. 15.34. Diagrammatic representation of lateral channels and their tributaries in a segment of leech.

posterior branches. These two branches join with their counterparts from the other lateral channel in the mid-ventral line and beneath the ventral channel forming *ventral commissure of the laterals*. There are eighteen such commissures in the segments between 6th and 23rd. The commissures of successive segments are in communication with each other through three *inter-segmental* and *longitudinal commissural branches*. Fig. 15.34 shows the disposition of lateral channels and their tributaries in a segment of leech.

There is no valve around the place of origin of the *latero-ventral* but valves are present in the place of origin of its branches.

The lateral channel receives a *latero-lateral* and *latero-dorsal branch* in each segment. The latero-lateral branches come from lateral body wall and from the nephridium of the same side and segment. The latero-dorsal is a large branch formed by the union of branches coming from dorsal and lateral body wall, the gut and nephridium of the same side and segment. Each latero-dorsal meets its fellow from the opposite side above the dorsal channel to form *dorsal commissures* of the lateral channels. There are seventeen such loops between 6th and 23rd segment.

In each segment *lateral commissures* join the latero-dorsals and latero-laterals.

Both latero-dorsals and latero-laterals are collecting vessels and pour their contents into lateral channel of the same side. The place of entrance of latero-dorsal and latero-lateral into the lateral channel is guarded by valves. The movement of fluid in the lateral channels is from behind forward.

Anteriorly both the lateral channels break up in the 5th segment into capillaries but posteriorly they open into the dilation of the ventral channel where a direct communication is formed between all the four channels (Fig. 15.35). Fig. 15.36 shows the disposition of haemocoelomic channels in transverse sections.

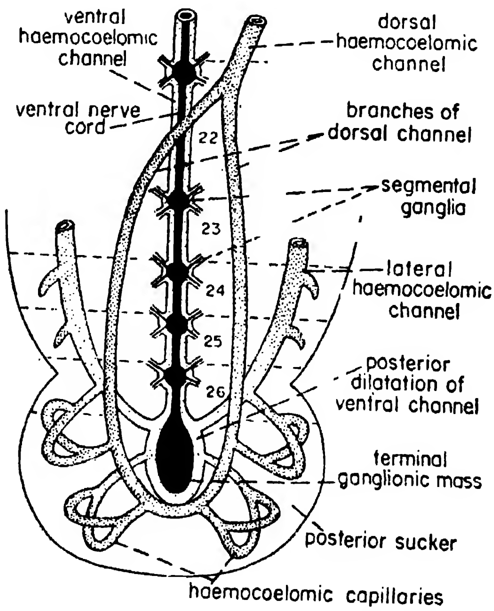


Fig. 15.35. Posterior end of leech showing the union of four longitudinal haemocoelomic channels.

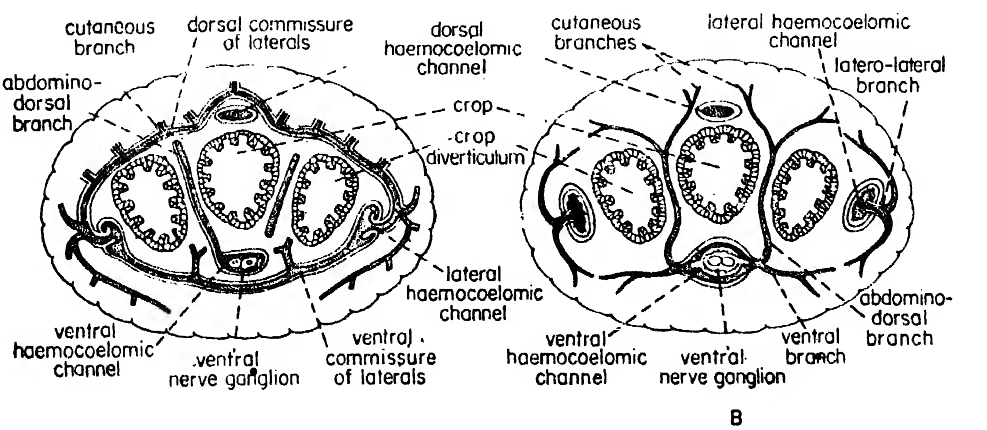


Fig. 15.36. Transverse sections of leech showing haemocoelomic channels. A = Dorsal and ventral commissures of lateral channels. B = Abdomino-dorsal and ventral branches.

Mechanism of blood circulation. The dorsal and ventral channels are distributory in function and the two lateral channels are both distributory and collecting in nature.

The dorsal channel supplies dorsal and dorso-lateral parts and the entire alimentary canal.

From dorsal and dorso-lateral body wall haemocoelomic fluid goes direct to the lateral channel through latero-dorsals. From alimentary canal the fluid runs through two latero-intestinals via dorsal commissures of the laterals.

The ventral channel supplies the ventral, ventro-lateral body walls and nephridia. The fluid from these parts returns to the lateral channels through latero-lateral and latero-dorsal branches.

Each lateral channel distributes to the nephridia, genital organs, gut and ventral body wall through latero-ventrals and receives back from these regions through latero-laterals and latero-dorsals.

Excretory system

Excretory system consists of *nephridia.* There are seventeen pairs of nephridia– one pair each in 6th and 22nd segments. Thus the first five segments and the posterior four segments are devoid of nephridia. Of these seventeen pairs, the anterior six pairs lie in the pre-testicular segments and are called *pre-testicular nephridia* and the remaining eleven pairs in the testicular segments, are called *testicular nephridia.*

Structure of a testicular nephridium. A typical testicular nephridium (Fig. 15.37) consists of (*a*) *main lobe,* (*b*) *apical lobe,* (*c*)

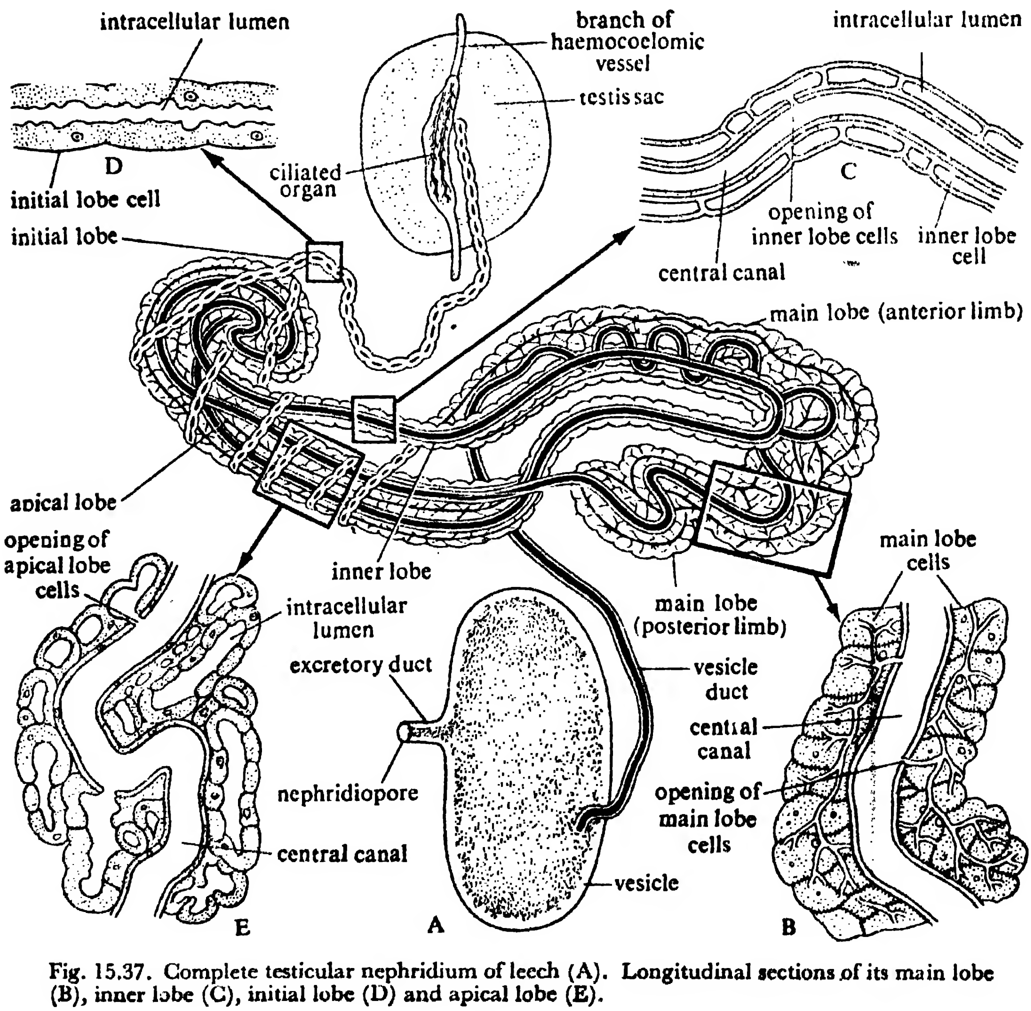


Fig. 15.37. Complete testicular nephridium of leech (A). Longitudinal sections of its main lobe (B), inner lobe (C), initial lobe (D) and apical lobe (E).

initial lobe, (*d*) *ciliated organ*, (*e*) *inner lobe*, (*f*) *vesicle duct* and *vesicle*.

(*a*) *Main lobe*. It is a horse-shoe-shaped structure and ventro-lateral in position. The main lobe consists of two unequal limbs, anterior and posterior. The anterior limb is larger in size than the posterior and the two together at their junction form the bend of the horse-shoe.

(*b*) *Apical lobe*. The posterior limb of the main lobe passes forward to form the stout apical lobe. It lies in an antero-posterior position beneath the gut. Its anterior end is bent upon itself.

(*c*) *Initial lobe*. It runs as an extremely long and slender lobe twined round the apical lobe. At its anterior extremity it runs as a slender thread of cells towards the testis sac and ends abruptly by the side of the *perinephrostomial ampulla*. While at its posterior extremity it joins the main lobe near the point of emergence of the vesicle duct.

(*d*) *Ciliated organ*. The ciliated organ lies in the peri-nephrostomial ampulla. It is a compound structure made up of a *central reservoir* and *ciliated funnels*. The reservoir is spongy in nature. The ciliated funnels are present in a large number on the wall of the reservoir. Each funnel is like an ear-lobe having a broad distal end and a proximal neck which fits into pores situated on the wall of the reservoir. The funnel is made of five to six cells arranged in two tiers and is densely ciliated. The ciliated organ has no excretory role in adult leeches and is associated with haemocoelomic system.

(*e*) *Inner lobe*. It lies in the inner concavity of the main lobe and runs forward along the outer border of the apical lobe about half its length.

(*f*) *Vesicle duct and vesicle*. The inner end of the anterior limb of the main lobe gives rise to a vesicle duct. The vesicle duct opens into the terminal vesicle. The vesicle is a large oval sac lying behind the nephridium and fixed to the ventro-lateral body wall. The vesicle leads into a narrow canal which perforates the body wall and opens to the outside by *nephridiopore*.

Histology of nephridium. The nephridium bears internally a central canal and in each lobe there are cells surrounding the canal.

Main lobe. Cells are large and polyhedral in shape. Each cell is provided with a narrow lumen which branches repeatedly and forms systems of fine capillaries which anastomose with those of neighbouring cells and open into the central canal.

Apical lobe. Cells are large and radially arranged round the central canal. The cells are pierced by intracellular canals. These canals join with one another to form a network which opens at places into the central canal.

Initial lobe. The initial lobe is very thin and is made up of a single row of elongated cells placed end to end. The cells are perforated by a continuous intracellular canal which gives off several diverticula in each cell. The canal ends blindly at the testis sac while its other end opens in the main lobe close to the place of origin of the vesicle duct.

Ciliated organ. The central reservoir is a spongy mass having an outer wall formed by a single layer of perforated cells enclosing a central mass of connective tissue cells and corpuscles. The funnels that fit in the pores of the outer wall are composed of five to six cells arranged in two tiers. The outer margin and the inner surface of each funnel are densely ciliated.

Inner lobe. The cells are elongated and tubular. The pores inside the cells are extensive and as a result a thin peripheral cytoplasm with nucleus is encountered. Five or six of these cells line the central canal.

Vesicle duct and vesicle. The vesicle is thin-walled and is lined internally with ciliated epithelium. The vesicle duct and the outgoing duct from the vesicle are both non-ciliated. A sphincter muscle is present round the opening of the outgoing duct from the vesicle.

Route of central canal inside the nephridium. The central canal follows a long and zigzag course throughout the body of the nephridium. It makes one complete and another incomplete round of run inside the body of the nephridium. The canal begins as a large intracellular lumen in a single cell at the anterior end of the *apical lobe*. Then it comes down the apical lobe to enter the *inner lobe* from where it goes to the posterior border of the anterior limb of the *main lobe*. From the main lobe, it passes along the outer

border of the apical lobe and on being embedded in it completes the first 'round'. The canal then loops backward and traverses the apical lobe. On reaching the posterior limit of the apical lobe it passes onto the *posterior limbs* of the main lobe. After traversing the main lobe and forming many loops in it the canal emerges from the posterior lip of the anterior limb and continues into the vesicle as vesicle duct. The second part of the canal is incomplete by one-fourth 'round'.

Pre-testicular nephridium

Structurally these nephridia resemble the testicular nephridia except that they lack ciliated organs. This is because the testis sacs in those segments are not formed. The initial lobes end loosely within the connective tissue on each side of the ventral nerve cord.

Role of nephridium and ciliated organ

In the body of leech the *haemocoelomic fluid*, i.e. blood and coelomic fluid, are not present as separate entities as they are in earthworm. The ciliated organ though considered along with excretory structures is totally separated from nephridium in an adult leech. The ciliated organ bathes in haemocoelomic fluid and has no excretory role. It is subservient to haemocoelomic system and manufactures haemocoelomic corpuscles. While the body of the nephridium minus the ciliated organ is richly supplied with lateral channels. It is excretory and osmoregulatory in functions.

Many workers believe that the Botryoidal tissues are excretory in nature.

Nervous system

The nervous system of Hirudinaria shows basic similarity to annelidian type as seen in earthworm (Fig. 15.38). But fusion of several anterior and posterior ganglia due to abbreviation of segments to form the anterior and posterior suckers, is a new feature.

The nervous system may be considered under three heads—(*a*) the *central nervous system*, (*b*) the *peripheral nervous system* and (*c*) the *sympathetic nervous system*.

(*a*) **Central nervous system.** It consists of a pair of closely-connected CEREBRAL GANGLIA in the fifth segment and lie above the roof of the pharynx. A triangular SUBPHARYNGEAL GANGLIONIC MASS is situated in the fifth segment and lies beneath the pharynx. It has been formed by the fusion of four pairs of ganglia. The cerebral ganglia and the subpharyngeal ganglionic mass are connected to each other by PERIPHARYNGEAL CONNECTIVES which form a stout ring round the pharynx. A VENTRAL NERVE CORD runs along the mid-ventral line from the subpharyngeal ganglionic mass to the TERMINAL GANGLIONIC MASS lying within the posterior sucker. The ventral nerve cord in reality is a double chain closely apposed to each other and bears 21 fused ganglia. The first annulus of the segments from sixth to twenty-sixth houses the ganglia. The terminal ganglionic mass is a large oval body formed by the fusion of seven pairs of ganglia. These seven segments constitute the posterior sucker.

(*b*) **Peripheral nervous system.** Nerves given off from the ganglia of the central nervous system of different parts of the body form the peripheral nervous system.

Each cerebral ganglion gives a stout branch to the eye of its own side and also gives fine branches to prostomium and roof of buccal chamber.

The subpharyngeal ganglionic mass gives off four pairs of nerves which innervate the 2nd, 3rd, 4th and 5th pairs of eyes. Nerves from this mass also go to the floor of the buccal cavity, muscles of the body wall and segmental receptors of the first five segments.

Each paired ganglion of the ventral nerve cord gives off two pairs of nerves, the *antero-lateral* and *postero-lateral*. The antero-lateral originates from the anterior part of the ganglion and continues through the first annulus to supply the body wall, sphincter around the nephridiopores and the receptors. Near its origin it gives off a branch from which finer branches arise to supply the nephridium, the vesicle and reproductive organs.

The postero-lateral originates from the ganglion and a little behind the antero-lateral. It bifurcates into two branches. One branch runs vertically upward to innervate the viscera and mid-dorsal region of the body wall while the other branch runs posteriorly along the ventral

body wall and supplies the testis sac, ventral part of the viscera and muscles.

(*c*) **Sympathetic nervous system.** It is present in the form of nerve plexus lying beneath epidermis within muscle layers of the body wall and on the wall of the

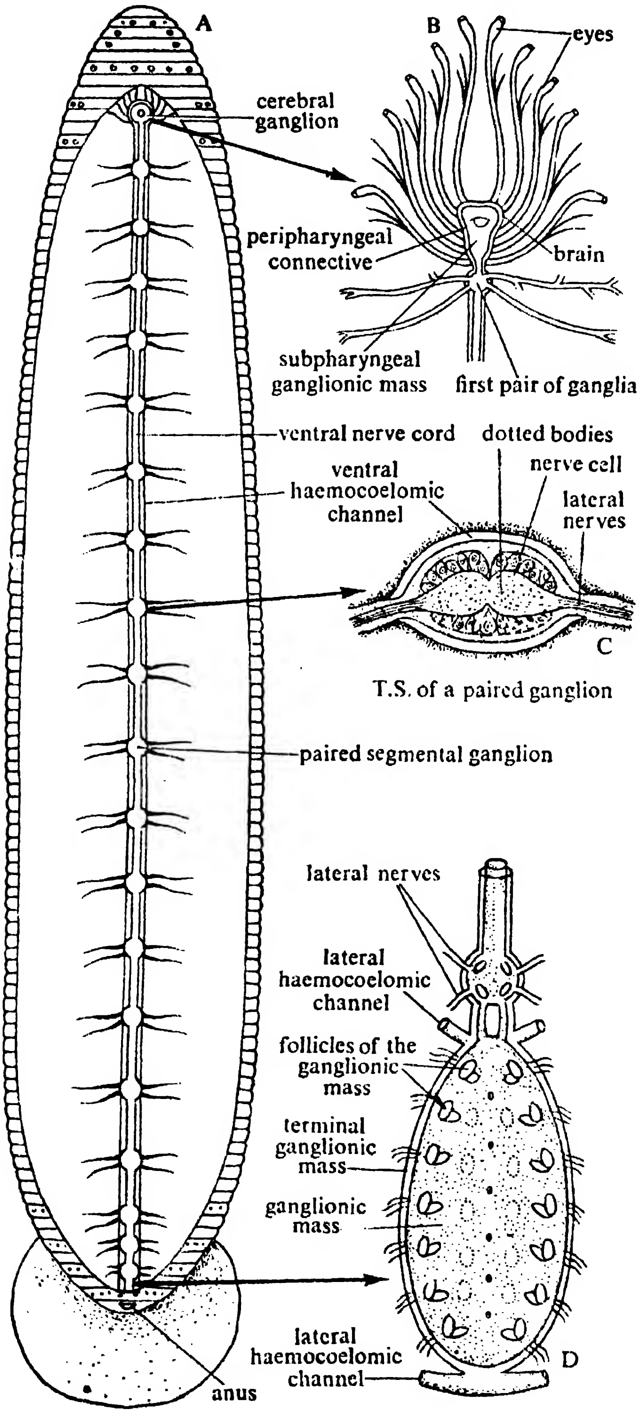


Fig. 15.38. Nervous system of leech (A). Enlarged view of its anterior part (B). Transverse section of a paired ganglion (C). Enlarged view of its posterior part (D).

alimentary canal. These plexuses are connected to the peri-pharyngeal nerve ring through scattered multipolar ganglionic cells.

Receptor organs

There are specially modified epidermal cells to serve as receptor organs (Fig. 15.39). These cells remain scattered and sunk within the body wall. In true sense, these cells cannot react themselves to the external stimuli but act as avenues of approach to the central nervous system. The different receptors found in leech are:

(*a*) **Eyes.** There are five pairs of eyes—one pair in each of the first five anterior segments. The first and second pairs of eyes are larger than the rest. The fifth pair are the smallest. The eyes are oriented in different directions. The first pair are directed forward, second pair forward and outward, the third upward, fourth backward and outward and the fifth backward.

Each eye is cylindrical in shape and the axis of the cylinder remains at right angle to the body surface. The broad outer surface of the eye is formed by a *convex epidermal layer* over which lies the *cuticle* (Fig. 15.39C). Both the cuticle and the epidermal layer are transparent. The rest of the cylinder are packed with cells arranged in longitudinal rows. Each cell is large, clear and refractile and bears a cresentic hyaline substance called *lens* or *optic organella* at the centre. The cytoplasm is peripheral and the nucleus is round in these cells. The walls of the cylinder enclosing these cells are pigmented and are called the *pigment cup*. An *optic nerve* enters in each cylinder at its basal end and runs along the middle line.

The cells within the cylinder are *photoreceptors*. It is not known whether the eyes can form images of external objects. It is reasonable to assume that the eyes can distinguish light from darkness and thereby can find out the direction or the source of light.

(*b*) **Annular receptors.** Arranged in a line across the middle of each annulus of a segment there are annular receptor organs (Fig. 15.39B). Each annulus bears eighteen such organs on its dorsal and eighteen organs on its ventral surface. These receptors are represented as papillae projecting out of the skin and are formed by a group of flattened and overlapping cells. The receptors are tactile in nature.

(*c*) **Segmental receptors.** These are present as elevated and elliptical papillae

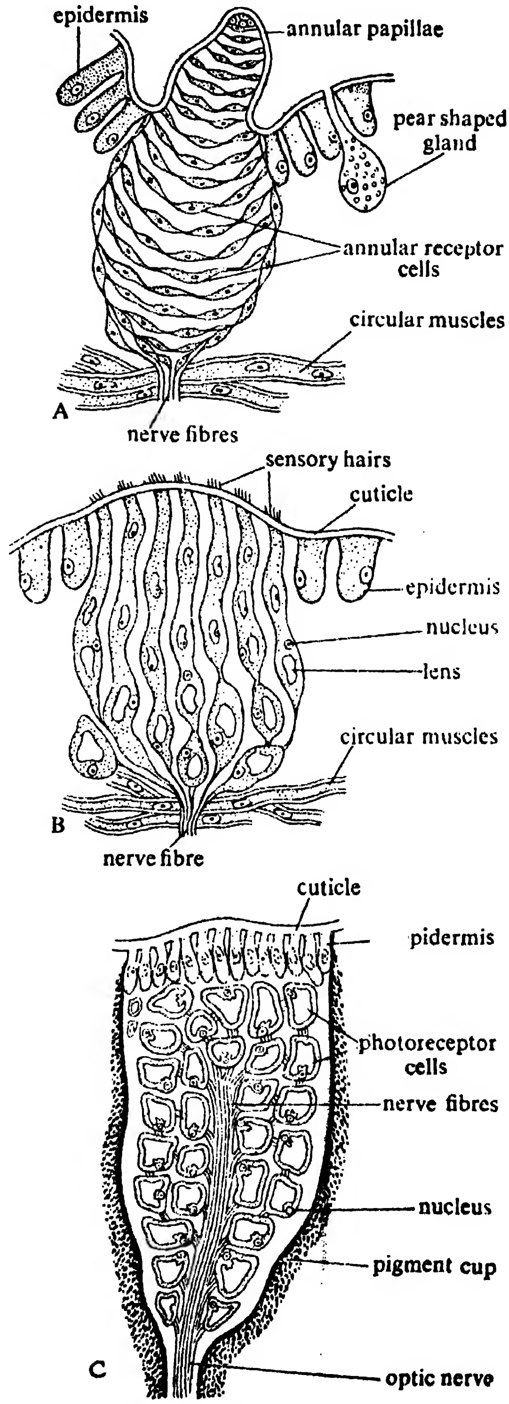


Fig. 15.39. Receptor organs of leech (sectional view). Annular receptor (A). Dorsal segmental receptor (B). Eye (C).

on the first annulus of each segment of the body. Four pairs of segmental papillae occur on the dorsal surface and three pairs on the ventral surface.

In each papilla there are ten to fifteen cells. The cells are elongated in shape and remain separated from one another by intercellular spaces. Each cell is provided with hair-like processes at its outer free end (Fig. 15.39B). The nucleus is oval and the cytoplasm is finely granular in each cell. The cells are tactile in function.

(*d*) **Free nerve endings.** These are simplest of all receptors and consist of a tuft of delicate fibres scattered between the epidermal cells of the body wall. These nerve endings help the leech to detect chemical changes in the watery medium in which it lives. Hence they are considered as chemoreceptors.

Reproductive system •

Hirudinaria is a *hermaphroditic* animal, i.e. both male and female reproductive organs occur in the same individual (Fig. 15.40). But they always practice reciprocal insemination during copulation.

Male reproductive system. It consists of (*a*) *testis sacs*, (*b*) *vasa efferentia*, (*c*) *vasa deferentia*, (*d*) *epididymis*, (*e*) *ejaculatory ducts* and (*f*) *atrium*..

There are eleven pairs of testis sacs. Each segment from twelve to twenty second houses a pair of sacs one on either side of the ventral nerve cord. The sacs are spherical in outline and whitish in colour. Being a part of the coelom the cavity is lined with coelomic epithelium and is filled with coelomic fluid. Spermatogonia or sperm mother cells are budded off fr m the inner walls of the sac. These cells float in coelomic fluid and later on develop into sperms. The *vasa deferentia* are a pair of longitudinal ducts running forward from 22nd segment to 11th segment along the ventral body wall. They are slender and lie one on either side of the ventral nerve cord. The testis sacs and the vas deferens of one side are connected by a very short and wavy duct called *vas efferens*. There

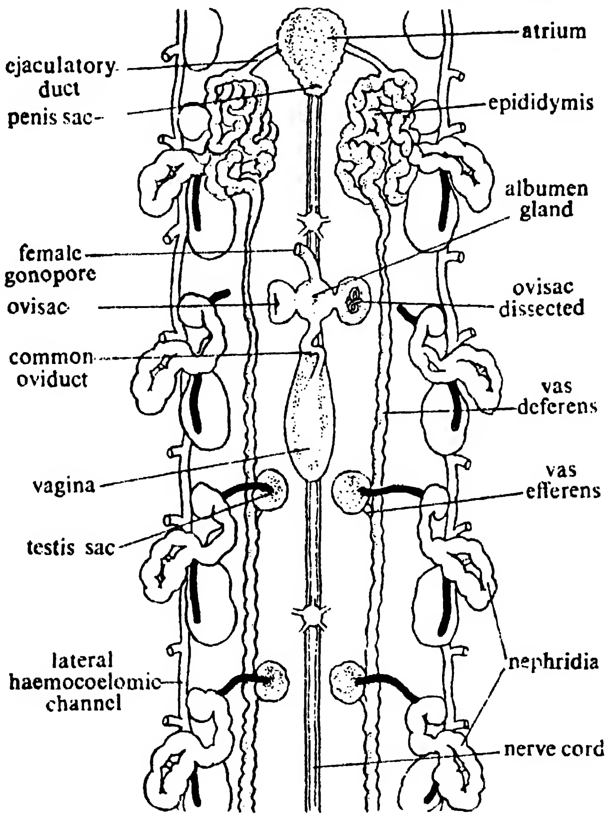


Fig. 15.40. Part of the body of leech showing a portion of ventral nerve cord, reproductive systems and a few nephridia.

are eleven pairs of vasa efferentia. The vasa deferentia become separate from the coelomic epithelial coverings in the middle of the 11th segment and form a pair of slender tubes. Each tube then turns inwards and becomes much convoluted to form the *epididymis*. A narrow and muscular *ejaculatory duct* arises from the anterior end of each epididymis. The ejaculatory ducts open into the *atrium*. The atrium is a pear-shaped organ lying mid-ventrally between 9th and 10th segments. It consists of an anterior swollen base, the *prostate* and a slender posteriorly directed neck—the *penis sac*. The prostate houses several layers of unicellular glands called *prostate glands* which pour their secretions through long ducts. The penis sac is muscular and bears a coiled and filamentous tube called *penis*. The penis is eversible.

The sperms are carried to the epididymis through the two vasa deferentia and they remain stored there. From each epididymis sperms pass to the base of the atrium where they are bound together to form packets of *spermatophores* by the secretion of the prostate glands. The spermatophores are transferred to the vagina of another leech during copulation through the tubular penis.

Female reproductive system. The female reproductive system includes (*a*) *ovisacs*, (*b*) *oviducts*, (*c*) *common oviduct* and (*d*) *vagina*..

There is only one pair of ovisacs situated in the 11th segment and very close to the ventral nerve cord. Each sac is coelomic in origin and contains a filamentous ribbon-shaped organ called *ovary*. The ovary appears as a nucleated cord of protoplasm with dilated ends. A short *oviduct* arises from the base of each *ovisac*. The two oviducts join to form the *common oviduct* in the 11th segment. The anterior part of the common oviduct is encased in a thick layer of *albuminous glands*. The glands are formed by cluster of cells which open into the common oviduct by individual ducts. The posterior part of the common oviduct takes a curved course and opens into the *vagina*. The vagina is a pear-shaped muscular structure which remains in the posterior part of the 11th segment and opens to the exterior by the female gonopore situated on the mid-ventral line of the 11th segment. The inner walls of the vagina are thrown into folds.

The ova originate as buds from the wall of the ovaries and pass onto the common oviduct where they become wrapped in albumen and ultimately they come down to the vagina and remain stored there.

Conjugation. Leeches practise cross-fertilization. During copulation two individuals come together and become applied to each other in a head to tail position and as a result the male gonopore of one individual lies apposed to the female gonopore of the other and *vice versa*. Consequently the penis of one gets into the female gonopore of the other, and there occurs a mutual exchange of spermatophores. The entire process continues for about an hour and then the individuals separate. Fertilization occurs inside the vagina. The usual breeding season is early spring.

Cocoon formation. In the mean time the glands of the clitellar segments secrete a snow-white foamy girdle around the clitellum. The leech then tries to free itself out of the girdle by wriggling. During this activity fertilized ova are squeezed out into the jelly of the girdle. The leech finally frees itself out of the girdle and the two ends of the girdle are quickly plugged by the secretion of prostomial glands. And thus a cocoon is formed. Cocoon formation takes about six hours to become completed.

Structure of cocoon. The shape of cocoon is like that of a barrel and it measures 30 mm in length and 15 mm in breadth. It is yellowish in colour and has a chitinous wall. The wall consists of an outer spongy layer and a tough inner layer. The narrow ends of the cocoon are provided with polar plugs with conical projections. The spongy layer encloses a large number of air bubbles which keep the cocoon afloat on water. The cocoon is filled with albumen in which float the fertilized ova. The cocoon may house one to two dozen of such ova.

Development and emergence of young leeches. Development is direct and occurs within the cocoon and the process is completed in about fifteen days. The albumen of the cocoon is used as food during development. When development becomes completed the polar plugs drop off and young leeches come out.

Example of the Phylum Annelida—*Polygordius*

Habit and Habitat

These marine animals live in seashores by holding sand grains or fine gravels with the help of secretions. They take minute algae by removing them from sand grains.

External structures

The body of *Polygordius* is slender, elongated, cylindrical and measures about 2–10 cm in length (Fig. 15.41).

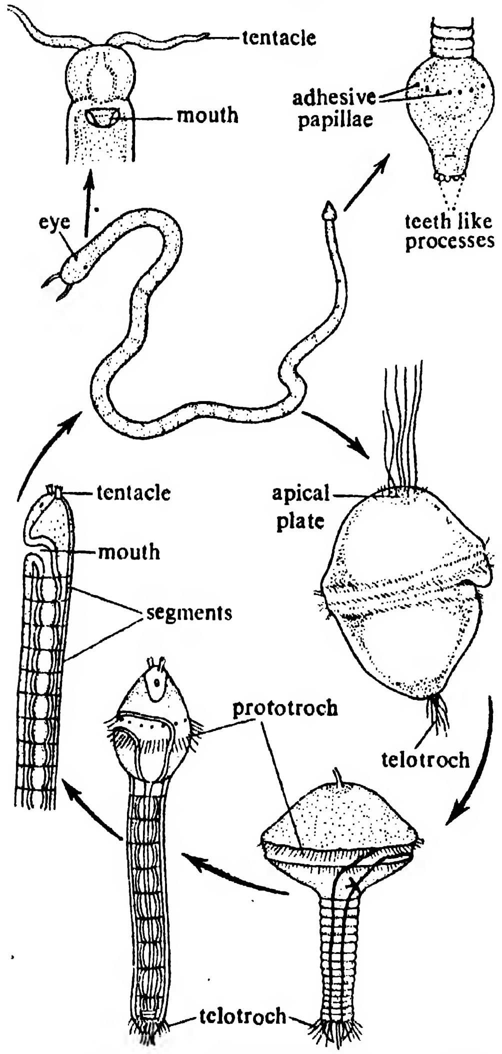


Fig. 15.41. Life cycle of *Polygordius* (after various sources.).

The segmentations are poorly marked, specially at the anterior part. Numerous identical segments are marked at the posterior part. The *prostomium* contains a pair of tentacles. The dorso-lateral sides of the body behind prostomium bears a pair of ciliated grooves. The *peristomium* is more developed than the prostomium. *Mouth* is ventrally placed near the junction of prostomium and peristomium. The posteriormost segment which contains *anus*, is broad and conspicuous. A series of tooth-like processes are present round the anus and a circlet of *adhesive papillae* lie in front of it. The parapodia are absent and setae are rarely seen.

Body wall

The body wall resembles that of other annelids but the layers of circular muscles are absent.

Coelom

The body cavity or coelom is largely obliterated. The septa are well-marked and complete.

Digestive system

The mouth leads into an alimentary canal which includes short, slightly protrusible *buccal chamber*, *oesophagus*, *stomach* and *intestine*. The entire length of the canal is internally lined by cilia. The anus becomes conspicuous due to the presence of tooth-like processes and adhesive papillae. The animals feed on small algae.

Circulatory system

The circulatory system is represented only by a dorsal and a ventral vessel which run longitudinally. These two vessels are connected by several transverse or lateral

Excretory system

The system includes a series of metamerically arranged *nephridia*, excepting in the first and last segments. The internal opening of each nephridium is situated on the proceeding segment and its external opening is called *nephridiopore*.

Nervous system

A pair of *cerebral ganglia* in the prostomium and a *ventral nerve cord* without segmental ganglia, represent the nervous system. The ventral nerve cord is embedded within the epidermis. The paired ciliated grooves which are present behind the prostomium probably act as sense organs.

Reproductive system

Sexes are separate. The females are usually larger than the males. Sex organs and ducts are not well recognised. Testis or ovary develops from the coelomic epithelium and the sex cells are discharged in the body cavity. In both the sexes, the reproductive cells are liberated by the rupturing of the body wall. Fertilization is external. The egg contains little yolk and the incidents of early development resemble that of *Nereis*. Here instead of epibolic movement of the micromeres the macromeres invaginate. The larva which is also called *trochophore* (Fig. 15.41) resembles in all respects the trochophore of *Nereis*. It is spherical and filled up with body fluid.

The adult worm is formed by posterior elongation and segmentation of the anal end of the trochophore. Each segment possesses a part of gut with enveloping mesoderm and ectoderm. The mesoderm in these segments split to give rise to coelom. The body gradually elongates and the trochophore shape remains as swollen 'head' of the metamorphosing larva. This end gradually transforms into the head of the adult.

The life history of Polygordius thus exhibits a scheme whereby a triploblastic coelomate organism may be evolved from a simple diploblastic gastrula; it also speaks about the origin of metameric segmentation.

Members of the class Archiannelida are considered as ancestral forms from which larger groups of annelids have been evolved. Addition of parapodia and setae and removal of ciliation and the connection between nervous system and epidermis in an archiannelid converts it to a chaetopod. Such resemblance speaks about their phylogenetic interrelationship.

SOME IMPORTANT ANNELIDS

In addition to the examples discussed, a large number of animals are seen which either belong to this phylum or are closely related to it. A brief account of a few interesting members are given below:

Polychaetes

This group includes heterogeneous forms where variation is marked not only in size but also in habits and structural organisation. Following examples will illustrate the range of diversities:

Arenicola. Burrows in sand; tentacles are absent; prostomium is fused with peristomium; body is distinctly divisible into three regions—anterior region with seven segments bearing setae, middle region of thirteen segments with branched gills and setae, and posterior region of several segments without gills or setae; nephridia are six pairs; possesses statocyst; build L- or U-shaped tubes within the burrows; tubes cannot be separated from burrows; gills are red in colour; ventral branch of parapodia has pads; reproductive cells are liberated through nephridia; maturity reaches after two years and the reproductive phase lasts for two weeks (Fig. 15.42A).

Sabella. Usually 10–25 cm in length; number of segments vary from 100–600; live within tubes which are made up of mucin and encrusted with mud; gill filaments arise from a semicircular base; filaments are of equal sizes; operculum is absent; long-ciliated faecal groove runs from the anus to the opening of the tube to throw out faecal matters; faecal groove runs dorsally along the thorax; prostomium is reduced and encircled by whorls of tentacles which are arranged like a funnel; blood is green (Figs. 15.42B-B_1).

Chaetopterus. Usually 15–25 cm in length; lives within parchment like U-shaped tube and is luminiscent; mouth is wide and funnel-shaped; gills are absent; peristomium is long; three pairs of parapodia situated in the middle of the body are long and act as fans to draw water inside the tube (Fig. 15.42E); reproduction is usually asexual and by transverse fission; several worms may live within one tube and also other animals may stay within the tube as commensals.

Amphitrite and **Terebella.** Both of them are tube-dwellers but can leave their tube to move like snakes; prostomium bears incompletely retractile multi-grooved tentacles; gills are three pairs and in *Terebella*, the third pair is small.

Serpula and **Spirorbis.** Live within tubes, which are formed by mucin impregnated with calcareous bodies; possess a crown of many tentacles derived from the prostomial palps; tentacles are feathery on both sides and one tentacle acts as operculum; ciliary feeding takes place;

tentacles are richly vascularised and act as gills; *Serpula* is 5–7 cm in length and has 200 segments. In *Spirorbis*, the body is grooved on one side and the groove acts as brood pouch.

Aphrodite. It is popularly known as 'sea-mouse' (Fig. 8.9G); body is usually broad and compact; hard jaws are absent in the proboscis; dorsal cirri are modified to form plate-like structure called *elytra* which act as gills; number of elytra vary from 15–20 and in addition to their function as respiratory structures the elytra produce water-current within the burrows; setal threads arise from notopodium and form an anstomosing network on the dorsal side; capable of digging burrows from 5–50 m deep.

Polynoe. Body is short and dorsoventrally compressed (Fig. 15.42D); provided with elytra like those of *Aphrodites;* proboscis bears four jaws.

Tomopteris. Pelagic; body is transparent; presence of one pair of lateral appendages at the anterior end; proboscis is unarmed and can be everted; parapodia are large and paddle-like, biramous and without setae; length usually 1·2–8·7 mm; one pair of eyes are present.

Autolytus. Size is small (Fig. 15.42C), usually 5–30 mm in length; teeth are present on the proboscis; parapodium is uniramous; presence of alternation of asexual and sexual generations—asexual forms develop from zygote by a process called budding. The process includes proliferation and construction at the posterior end and such buds develop into sexual generations. Males and females are different and both are dissimilar to the parent as regards the appearance of parapodia and setae.

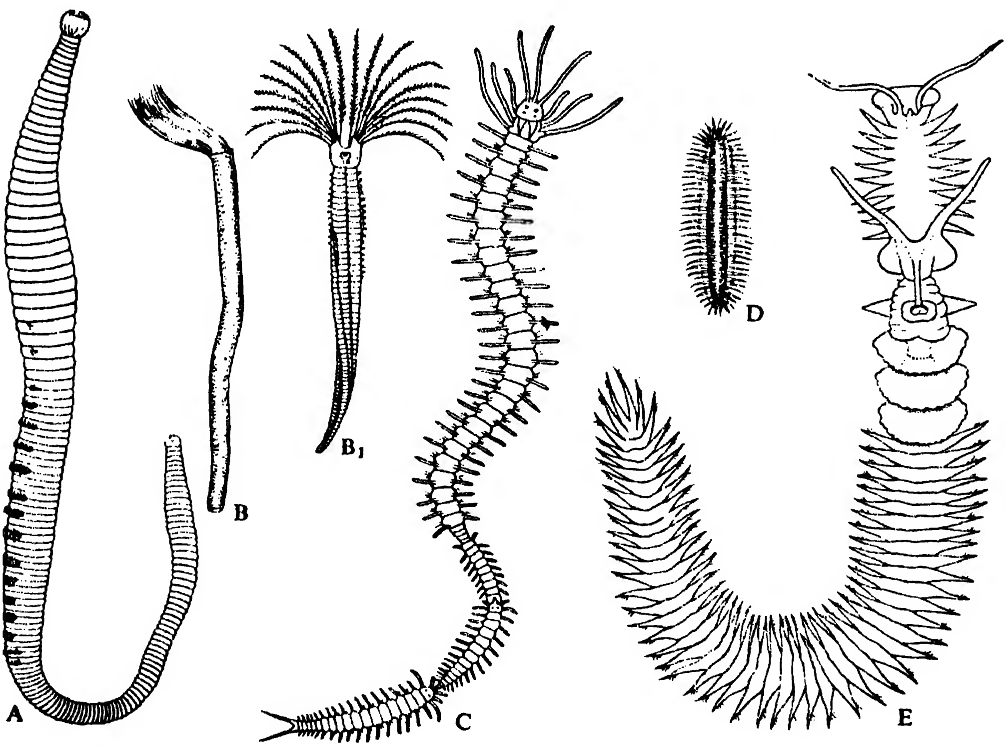


Fig. 15.42. Some interesting annelids (after various sources). A. *Arenicola.* B. *Sabella* within tube. B₁. *Sabella* outside the tube. C. *Autolytus.* D. *Polynoe.* E. *Chaetopterus.*

Eunice. Elongated body having eversible proboscis with tooth plates and teeth; presence of cirrus in place of dorsal parapodium; notopodium bears a branched gill; setae are straight; length varies from 3–70 cm in different species and some may contain more than 500 segments (Fig. 8.9F).

Oligochaetes

The oligochaetes are simple and compared to the polychaetes they are less varied. The aquatic members are much smaller than the terrestrial forms; in aquatic form male genital aperture lies in front of the femalea perture. Some well-known forms are discussed below:

Megascolex. Terrestrial and large sized; presence of several nephridia in each segment.

Tubifex. Length varies from 2·5–8·5 cm; red in colour; anterior part of the body remains within a tube of mucus and the posterior end waves rapidly. With the slightest disturbance in the environment, the worms withdraw the body within the tube. With the decrease of dissolved oxygen in water, the worm increases its extension from the tube; reproduction is asexual.

integument; presence of asexual reproduction at regular intervals, resulting into the appearance of chains of zooids which after separation becomes sexually matured.

Aeolosoma. Prostomium large and bears cilia (Fig. 15.43A); cuticle is without segmental groove and septa are confined to loose muscles; reddish-yellow droplets are seen in the epidermis; organs for sexual reproduction are present, but usually asexual reproduction takes place.

Hirudinea

Nearly 300 species of leeches exhibit a uniformity in their appearance and structure. All are hermaphrodites and are devoid of typical annelid appendages like parapodia. Body is usually adapted for living as ectoparasite. Some interesting members of this group are discussed below (Fig. 15.43 B–F).

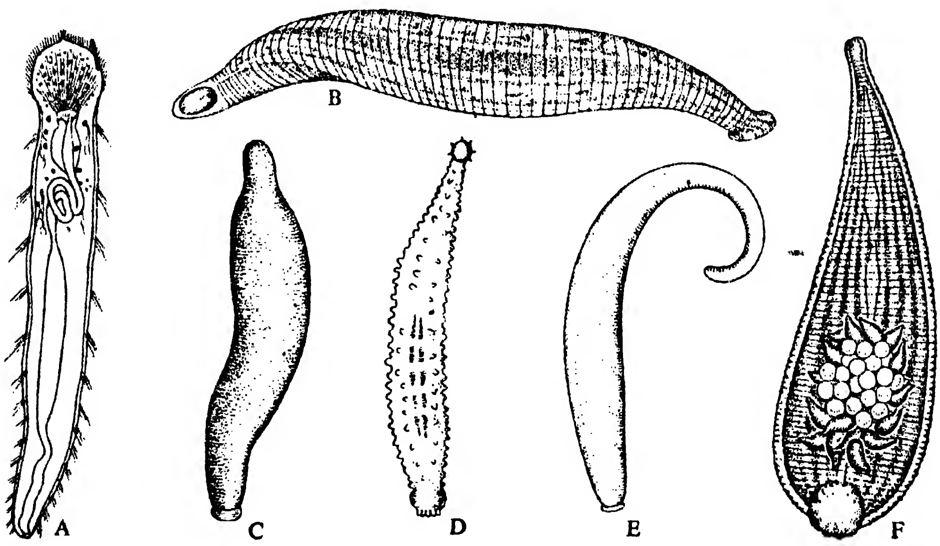


Fig. 15.43. Some interesting annelids (contd.) (after various sources). A. *Aeolosoma*. B. *Hirudo medicinalis*. C. *Haemopis*. D. *Pontobdella*. E. *Acanthobdella*. F. *Glossiphonia*.

Allolobophora. Length varies from 2·5–17 cm; usually ringed with maroon and yellow; some species are polyploid; one species (*A. rosea*) is parthenogenetic.

Eisenia. Usual length is 6–13 cm; each segment with a red or brown band; presence of a stinky odour.

Chaetogaster. Usual length is 0·1–1·5 cm; possesses distinct segmental grooves and septa; carnivorous; internal structures are distinctly visible through the transparent

Haemadipsa. Length is variable—2·5 to 8 cm; terrestrial; possesses three jaws; can move very rapidly.

Haemopis. Usual length is 10–30 cm; colour is greenish-black; presence of 14 blunt teeth on the jaws in two rows; usually parasitic on horses. Some species of *Haemopis* are predators and can swallow an earthworm.

Branchellion. Marine and parasitic on ray fishes; cylindrical body with bell-like

anterior sucker; one part of the body is narrow and the other part is broad; presence of foliaceous respiratory plates on the lateral sides of the body.

Pontobdella. Marine and parasitic on bony fish; most features resemble *Branchellion*, only difference is the presence of leathery skin with knob-like structure.

Acanthobdella. Length is usually 2–37 cm; lives as a parasite on Salmon fish and in addition to blood, eats skin and fin tissues; anterior sucker is absent; anterior part is flattened and here each segment bears two pairs of setae.

Glossiphonia. Body is dorso-ventrally flattened but oval in outline; length is 0·5–3 cm; parasite on fresh-water snails and aquatic insects; anterior sucker is flat but posterior sucker is cup-like; three pairs of eyes are present; a ventral groove carries the eggs and young ones.

Hirudo. Common medicinal leech is known as *Hirudo medicinalis;* dark green body with six red, yellow or brown coloured clongated bands; presence of 100 sharp teeth; size of cocoon is 2–3 cm in length.

Echiurids

This group includes 150 species, of which the largest is *Ikeda taenioides* (185 cm). All are marine and possess a long proboscis, spacious coelom, metanephridia and fairly simple vascular system. The features of a few interesting members of this group are given below:

Bonellia. It exhibits extreme sexual dimorphism—female with large oval and green coloured body and minute male (3 mm) lives within the female (Fig. 15.44). Nearly 85 males are seen within the foregut of a female. A few reach up to the distal end of the metanephridia and as it acts as reproductive duct, these males get the opportunity to fertilize the ova. In female, the proboscis is very long (1 m) and its terminal end is bifurcated as arms. The body of the female has numerous papillae and integument has poisons for protection. The proboscis has a groove on its ventral side which leads into mouth near the anterior end of the body. The minute male has an outer ciliated covering, but proboscis, mouth and anus are absent. Most part of gut is converted into sperm duct. Development involves the appearance of a free swimming larva with much yolk. According to their genetic make-up all the larvae are females in the beginning. One which comes in contact with a female becomes male otherwise it develops as a female.

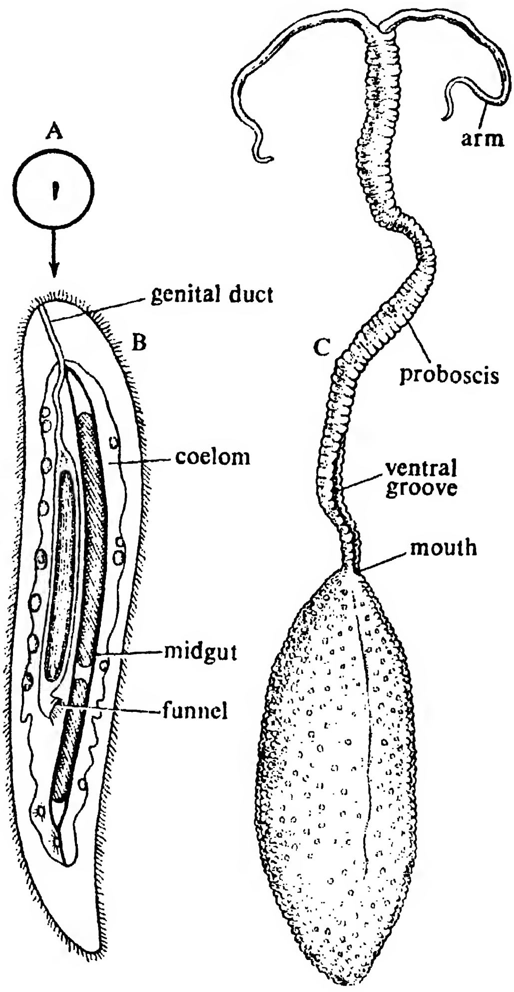


Fig. 15.44. *Bonellia* (after various sources). Male (within a circle) shown in proportion to the size of a female (C). B. Enlarged view of the male to show inner details.

Echiurus. Segmentation is superficial; trunk is barrel-shaped; prostomium forms proboscis and it exceeds the length of trunk (Fig. 15.45A); a broad ciliated band is present on the ventral side of the proboscis, it is called *gutter;* presence of two whorls of setae at the posterior end; presence of insignificant brain and a single ventral nerve cord; always live within U-shaped burrows which are dug by bending the proboscis and the anterior part of the trunk; can swim by spiral

twisting and extension of trunk; food includes minute organisms like diatoms, protozoa, algae, etc. While feeding, it extends the proboscis from the burrow and rolls it along the bottom of the water; ventral cilia brush up the microscopic food and mix it with mucus. The margin of the ciliated band or gutter forms a funnel through which food is directed to the mouth; one pair of thin walled anal sac with numerous ciliated funnels act as excretory organ which open to the rectum; sexes are separate; two metanephridia act as reproductive duct; larva is a plankton and resembles the trochophore.

Sipunculids

This group includes nearly 250 species of which the largest is *Siphonomecus multicinctus* (nearly 51 cm). The other important genera are *Sipunculus* sp. (Fig. 15.45B), is present at the tip of the introvert and around the margin of the mouth the introvert membrane is fringed and funnel-shaped in *Sipunculus* but tentacle-like in other (*Golfingia*). The other surface is covered by a chitinous cuticle and is iridescent in *Sipunculus*. Beneath the epidermis the body wall is represented by circular, diagonal and longitudinal muscle layers within which epidermal gland cells are embedded. Ciliated coelomic epithelium lines the spacious coelom which extends within the trunk, tentacles and within the cuticle in *Sipunculus* as *cuticular canal*. The fluid within coelom is in constant circulation by the movement of cilia and it includes—wandering *leucocytes*, disc-like *hemerythrin* containing cells, reproductive cells and excretory cells. The extension of introvert and tentacles are caused by regulating the flow of coelomic fluid. The oesophagus

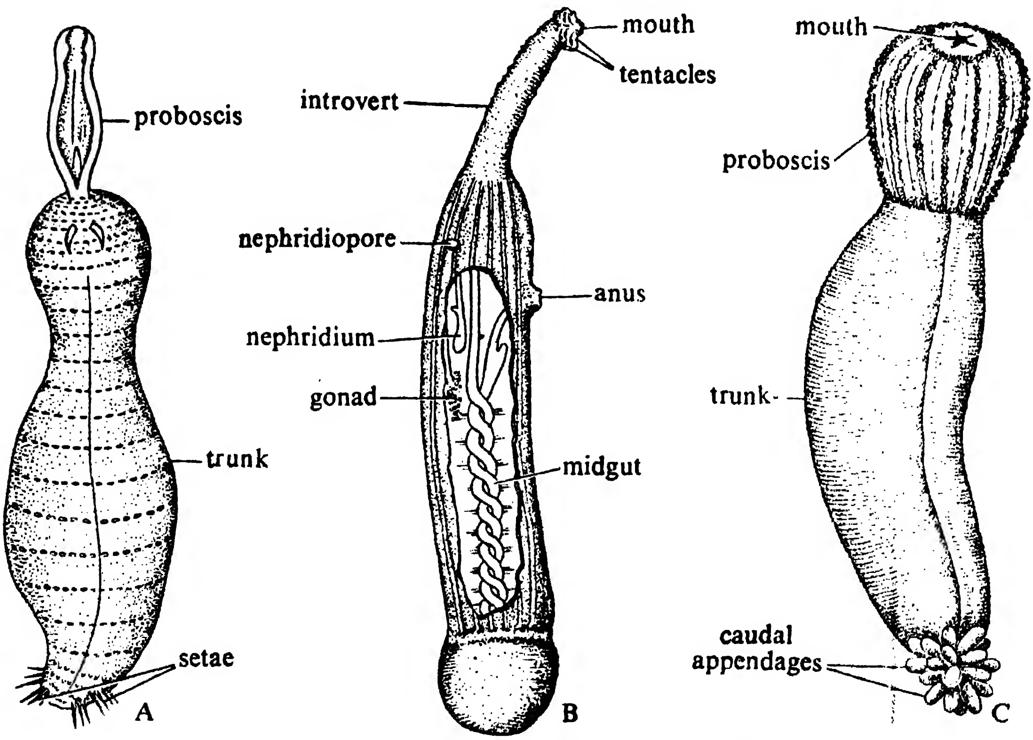


Fig. 15.45. A. *Echiurus* (ventral view). B. *Sipunculus* (partly dissected to show the internal organs). C. *Priapulus* (after Kaestner).

Golfingia sp. and *Phascolosoma* sp. These marine animals usually possess a body, divisible into *trunk* and a narrow *anterior end*. The anterior end can be involuted inside the trunk and thus is called *introvert*. In certain forms the extended introvert may exceed the length of the trunk. Mouth is ciliated and the remaining part of the canal first runs posteriorly and then coils in anterior direction to open through anus which is near the base of introvert. Chloragogen cells and a pair of metanephridia are responsible for excretion. The nephridia are present within the anterior end of

the trunk and open near the anus through a separate opening called nephridiopore. The nephridia also convey matured reproductive cells. The chloragogen cells are present on the lining of the coelom over the intestine. After collecting excretory products these cells drop in the coelomic fluid. Locomotion includes crawling and swimming. Both are caused by the contractile action of introvert and longitudinal body muscles. Nervous system includes a two-lobed brain and a single median posteriorly directed ventral nerve cord. Brain is present near the mouth. The skin acts as respiratory surface and the hemerythrin in disc-shaped coelomic cells is responsible for binding oxygen. Sexes are separate and the reproductive organs are present in the coelomic epithelium of the anterior trunk region. Fertilization is external and larva resembles the trochophore.

Priapulids

This group includes only 8 species of which the largest is *Priapulus caudatus*. The body is divisible into a spiny anterior introvert and a posterior trunk (Fig. 15.45C). The introvert bears mouth, pharynx and brain but is without tentacles. Double-layered cuticle is present which is made up of chitin and proteins. Sensory papillae are scattered all over the body. Coelom is large and filled up with fluid-containing several cell-types. One or a few caudal appendages are present at the posterior end of the body to act as respiratory organs. The intestine is straight and on each side of the intestine lies a urinogenital organ. Each urinogenital organ includes a *protonephridial duct*, at the one end of which lies numerous *solenocytes* for excretion and the other end bears the *gonads*. Entire structure is enclosed by a membrane and remains attached with the body wall. The urinogenital organ opens through a pore near the anus. Moulting is very quick and is completed within a minute. Fertilization is external and the non-ciliated larva becomes adult after two years.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

PHYLUM ANNELIDA

A. Class **Chaetopoda**

Order *Polychaeta*, e.g. *Nereis*, *Syllis*, *Glycera*.

Order *Oligochaeta*, e.g. *Pheretima*, *Lumbricus*, *Tubifex*.

B. Class **Hirudinea**

Order *Acanthobdellida*, e.g. *Acanthobdella*.

Order *Rhyncobdellida*, e.g. *Pontobdella*, *Glossiphonia*.

Order *Gnathobdellida*, e.g. *Hirudo*, *Haemadipsa*.

Order *Herpobdellida*, e.g. *Herpobdella*, *Orobdella*.

C. Class **Archiannelida,** e.g. *Polygordius*, *Protodrilus*.

Appendix to the Phylum

Order *Sipunculida*, e.g. *Sipunculus*, *Phascolosoma*.

Order *Priapulida*, e.g. *Priapulus*.

Appendix to Class Chaetopoda

Myzostomidae, e.g. *Myzostoma*, *Stelechopus*.

CLASSIFICATION WITH CHARACTERS

Class **Chaetopoda.** Metameres are numerous, distinct and similar; metameres bear setae or parapodia; setae are lodged in setigerous sacs on the epidermis; coelom is internally divided into compartments by septa; blood-vascular system is well-developed, ventral nerve cord contains several ganglia.

Order *Polychaeta*. Sexes are distinct; reproductive organs are simple and segmentally repeated; distinct head with eyes and tentacles is present; parapodia are well-developed bearing numerous and long setae; structures like cirri and branchiae may be present; clitellum is always absent; metamorphosis is present; larva is a trochophore; mostly marine. This order is divisible into two suborders—*Errantia* and *Sedentaria*. The Errantia includes examples like *Nereis*,

Most modern workers divide the Phylum Annelida into three main classes:

I. Polychaeta (including marine forms).

II. Oligochaeta (including terrestrial and freshwater forms).

II. Hirudinea (including terrestrial, fresh-water and marine leeches).

Besides the above three major classes, two minor classes are recognised. They are:

I. Myzostomaria.

II. Archiannelida.

Syllis, *Autolytus*, *Glycera*, *Aphrodite*, *Polynoe* and *Eunice*. In all of them, head is distinct and trunk bears parapodia which are all alike. In Sedentaria, head is indistinct and trunk is divisible into thorax and abdomen. The segments and parapodia are dissimilar. The common examples are *Chaetopterus*, *Arenicola*, *Terebella* and *Sabella*.

Order *Oligochaeta*. Head is insignificant; clitellum is present; parapodia and cirri are absent; setae are simple; no development without metamorphosis; usually hermaphrodite; mostly terrestrial and fresh water forms, e.g. *Pheretima*, *Lumbricus*, *Tubifex*.

Class **Hirudinea.** Body consists of definite and limited number of segments; segments are marked externally by secondary annuli; usually with a suctorial anterior sucker and a powerful posterior sucker; coelom is reduced by the presence of connective tissue called the botryoidal tissue; both sinuses and muscular blood vessels are present; hermaphrodite; development is direct; terrestrial, fresh water or marine; either free-living or permanent or intermittent parasites.

Order *Acanthobdellida*. Proboscis is short; anterior sucker is absent, e.g. *Acanthobdella* (parasite on fishes).

Order *Rhyncobdellida*. Anterior part of the body can be protruded or retracted as proboscis, e.g. *Pontobdella* (parasite on fishes), *Glossiphonia* (parasite on snails and frogs).

Order *Gnathobdellida*. Anterior and posterior suckers are developed; mouth is provided with two or three toothed jaws, e.g. *Hirudo* (the typical leech which is a parasite on vertebrates), *Aulostoma*, horse-leech, (free-living and carnivorous), *Haemadipsa*, the land leech.

Order *Herpobdellida*. Mouth is not provided with jaws, e.g. *Herpobdella*, *Orobdella*.

Class **Archiannelida.** Most of the modern workers are of opinion that the archiannelids are the specialised aberrant members of other annelidan families. The status given to the archiannelids as the class is an artificial one. The archiannelida are unisexual, i.e. the sexes are separate; small in size; external segmentations are indistinct, setae or parapodia are usually absent; larva is trochophore; marine, e.g. *Polygordius*, *Protodrilus*.

Appendix to the Phylum

Order *Sipunculida*. Adults are without segmentation, anterior part of the body is invaginable; parapodia or setae are absent; mouth is with tentacles; anus is anterior and dorsal; coelom is not divided by septa; presence of a single pair of nephridia; sexes are separate; larva is a modified trochophore, e.g. *Sipunculus*, *Phascolosoma*.

Order *Echiurida*. Adults are unsegmented; general shape is oval or cylindrical; mouth is anterior and anus is posterior; overhanging mouth is a long and solid proboscis (except *Saccosoma*); proboscis is sensitive and mobile; parapodia are absent; possess a pair of ventral setae (except *Saccosoma*); coelom is undivided; intestine is much coiled; a siphon is associated with the intestine at both ends; the siphon is an elongated tube having a ciliated groove; a pair of anal vesicles as sole excretory organ which open in the rectum; sexes are separate with sexual dimorphism; marine; larva is trochophore, e.g. *Echiurus*, *Thalassema*, *Bonellia*.

Order *Priapulida*. Unsegmented but with superficial annulations; proboscis is beaded with small spines; mouth has chitinous teeth; tentacles are absent; alimentary canal is straight; blood-vascular system is absent; nephridia are absent; gonads are with paired ducts which also serve in excretion; branchae are present; sexes are separate; marine, e.g. *Priapulus*.

Appendix to Chaetopoda

Myzostomidae. Disc-shaped body (in some cases elongated) which is devoid of external segmentation; patches of cilia are present on dorsal and ventral surfaces; presence of five pairs of parapodia with hooks and supporting rods; in between the marginal parapodia there are four pairs of suckers; ten or more pairs of cirri round the margin; pharynx can be protruded as proboscis; coelom is indistinct being packed with parenchyma; no blood-vascular system; a single pair of nephridia with nephridial funnel and nephridiopores; nephridiopores open in cloaca or to the surface, hermaphrodite; live as internal parasites of crinoids and starfishes, e.g. *Myzostoma*, *Stelechopus*.

GENERAL NOTES ON ANNELIDA

Members of the phylum Annelida are widely distributed. In habit, form and structure the annelids show great diversity. The structural features of the annelids are of considerable importance in interpreting those of still higher types of animals like arthropods and chordates and as such they are considered as valuable forms for study.

HABIT AND HABITAT

Most polychaetes are marine. Larger forms like *Aphrodite*, *Glycera* live in mud while slender and smaller forms live in water spaces between sand grains. Many forms like *Polygordius*, *Protodrilus* secrete sticky substances and remain attached on sand. In some forms the setae are used in attachment to the sand. *Nereis vitabunda* of Sumatra is a terrestrial form and lives in soil channels. Most polychaetes on being transferred to fresh water die, while a few species like *N. diversicolor*, *Troglochaetus* can withstand and live in fresh water.

Oligochaetes are fresh water animals though a few of them like *Helodrilus* are marine. Most oligochaetes are terrestrial and live on mud-shores, in forests, meadow and cultivated lands. In Borneo, a group of earthworms under the genus *Pheretima*, climb trees and live on barks and leaves of trees.

Seventy-five per cent of the members of the class Hirudinea live in fresh water and are very common in marshes and ponds. South American soil leeches (*Erpobdellidae*) live in moist soil, cow dung and rotten wood and act as predators of worms and insects. Terrestrial leeches usually live in moist vegetation of the tropics and feed on the blood of vertebrates. *Pisicola geometra* is a brackish water form and remains attached to bottom-dwelling fishes. *Branchellion* is found attached to skates and rays.

Echiurids are semisessile and marine animals. Many forms live in burrows, and cavities made by other animals or on empty shells of molluscs.

Annelids vary widely regarding their sizes. Most polychaetes are minute to moderate in size but *Neanthes brandti* of Californian coast attains a size of about 1·5 metres. Oligochaetes like *Chaetogaster*, *Aeolosoma* are a few cm in length but a few attain giant size. *Rhinodrilus fafneri* of Ecuador and Australian *Megascolides australis* grow over two meters in length and 25 mm in diameter. The average length of leeches is between 10 and 200 mm.

GENERALISED CHARACTERS

The annelida as the name implies (annulus = ring) are segmented worms and the segments in many cases are externally recognised as ring-like constrictions. In many forms a distinct head consisting of a pre-oral '*prostomium*' and a post-oral '*peristomium*' is present. In most of the forms anterior, posterior, dorsal and ventral surfaces are well-recognised. The food canal is a straight tube with demarked regions and extends from anterior mouth to terminal anus. In many forms the perivisceral cavity or coelom is well-developed. The coelom is lined with mesoderm and communicates to the exterior through paired *nephridia*. The body wall is muscular having circular and longitudinal layers of muscles and many have *setae* embedded in skin. Typical members have thin and non-chitinous cuticle. The blood-vascular system is of closed type. The organs of excretion are metamerically arranged *tubular nephridia* or *segmental organs* which are closed internally or lead from coelom to exterior. A series of paired ducts called *coelomoducts*, either united with or distinct from the nephridia may be present to carry the reproductive elements outside. The central nervous system consists of a pair of pre-oral ganglia connected by commissure with a pair of ventral cords which is expanded at each segment to form ganglion. Development may be direct or indirect. The larva is called *trochophore* and undergoes metamorphosis.

SPECIALISED CHARACTERS

In Annelids the *triploblastic* condition has attained perfection. The body cavity is a true coelom which lies between the body wall and the tubular food canal. The body plan may be best described as a tube within a tube. This structural plan is maintained in higher forms. Definite segmentation is encountered in annelids. The body is composed of numerous distinct segments arranged in a linear series.

Bilateral symmetry is well represented in annelida and this is an evolutionary advancement over more primitive radial symmetry. Nervous system of annelids is more organised and consists of a pair of dorsally-placed cerebral ganglia and ventral nerve cord. The nerve cells are distributed in the nerve cord and ganglia. The tendency of 'Head' formation is distinct. Head is usually associated with sense organs and as the sense organs help the animal to keep in touch with the surroundings, they are usually housed at that end of the body which remain directed forward during locomotion. Organs and organ systems performing vital functions as nutrition, excretion and reproduction are highly developed in annelids. Thus association of differentiated tissue groups has occurred in them.

SEGMENTATION AND COELOM

The annelids show the unique structural developments which are retained in higher forms of animals. These structural developments are segmentation and coelom.

Segmentation or metamerism is an architectural body plan in which an organism is built by a series of segments or metameres. A segment generally contains a pair of nerve ganglia, a pair of appendages and a pair of coelomic sacs. In all respects the segments forming an individual are identical in structure and the organs they contain or in other words, the individual is formed by rhythmic repetition of segments which are similar both externally and internally. This repetition is often disturbed by simplification, by coalescence of segments or by differentiation between the segments. In annelids there is a pair of sacs—the right and left *coelomic vesicles* lying between each segment of the gut and the corresponding segment of the body wall. The cavities of the coelomic vesicles contain a fluid and corpuscles and are lined by *peritoneum* derived from *mesodermic epithelium*. Each segment of annelida has a *dorsal mesentery, ventral mesentery* and a *septum*.

Two sheets of peritoneum meeting in the mid-line above and below the gut form the dorsal mesentery and ventral mesentery respectively. The septum which is a screen between two successive segments is formed by the meeting of two peritonial sheets at the boundary between the segments. In rare exceptions, the septa and mesenteries form a complete series of transverse or longitudinal partitions throughout the entire length of the body of the animal. In most cases the septa are perforated and the mesenteries are incomplete so that there exists a close communication between coelomic vesicle and coelom.

The wide space between the gut and internal body wall is the *coelom*. It arises from segmental vesicles and is lined by mesoderm on all sides. The coelom plays a great role in the life of all animals. Where it is present its fluid content facilitates smooth transportation of particles or materials in solution. Coelom affords flexibility to the body and extends room for the movement of the gut which remains suspended. Gonads which develop from coelomic epithelium are housed in the cavity of the coelom. So also are the nephridial tubules, which connect the coelom to the outside and which in some cases allow the passage of eggs and sperms.

Special features of coelom. Developmentally coelom arises as a split in the mesoderm which becomes bifurcated into two layers, a *somatic layer* lying next to the epidermis and a *splanchnic layer* around the endoderm. Thus coelom becomes bounded on all sides by coelomic epithelium which secretes *coelomic fluid*. The greater part of the coelom forms the *perivisceral* cavity or *splanchnocoel*. It is a fluid-filled space inside which is lodged the viscera. Because of this packing the viscera remains independent of the movements of the muscles of body wall. In some higher animals part of the perivisceral cavity is kept separate to form restricted cavities whose coelomic nature can and only be realised if their developmental history is followed. In some coelomate animals such as molluscs and arthropods the cavities of the blood-vascular system become greatly enlarged and this enlargement obliterates the perivisceral coelom and as a result the viscera lies in a spacious cavity filled with blood. This blood-filled cavity is called *haemocoel*.

In all probabilities the ancestral coelomate animals had segmentally arranged mesodermal pouches. From these pouches gametes were formed by the process of

proliferation of the epithelial lining. Later on, these pouches became modified in structure and function. The evolution of mesodermal pouches is evident in present-day coelomates.

Each mesodermal pouch in ancestral coelomates was provided with a pair of ducts called *coelomoducts* which served as a passage for the exit of gametes and a single *nephridial tubule*, for the removal of nitrogenous wastes. These primitive nephridia resembled the platyhelminthic type of excretory organs. That is, they consisted of ectodermal tubules projecting into the coelom and ending in specialised cells called *solenocytes*.

In many polychaetes the coelomoducts and nephridium do not remain independent but fuse to form compound organs called *nephromyxia* which carry on dual function of excretion and transportation of gametes to the exterior. In many forms the nephridium ends blindly in the body cavity while in majority the nephridium acquires an opening into the coelom by means of *nephrostome*. Thus it becomes possible to convey excretory matters collected from coelom directly to the outside. Attainment of nephrostome by the nephridium causes great reduction of coelomoduct system which is then represented as *ciliated organs*.

Segmentation in Annelids. The types of segmentation occurring in annelids and strobilation of tapeworms offer some confusion but basically the two types of organisation are different. The body of annelids consists of a number of segments and the number remains constant in a given species except in certain cases of asexual reproduction. New segments are not added to the body after maturity is reached. That means after the embryonic stage all the segments become of same age. Moreover, the segmental structures are interdependent and integrated so that the individuality of the body is preserved. The condition is some what different in tapeworms where the segments of the body are self-contained units and new segments are always formed.

Cephalization. A well-defined and well-organised head is lacking in annelids. However, formation of a 'head' is suggested in polychaetes by anteriorly placed structures and their association with parapodial cirri. In some polychaetes transformation of one or two post-oral segmental parapodia into protostomial cirri has occurred. This transformation is accompanied by a shift of these post-oral segments and their ganglia anterior to mouth (pre-oral), resulting some sort of a brain formation. Cephalization in true sense is absent in annelids but in them an indication of the things to come is given.

BODY WALL

The outer tube or the body wall is made up of (*a*) *Cuticle*, a thin and transparent membrane over the epidermis. Chemical nature of the cuticle is supposed to be a mixture of protein and polysaccharide. (*b*) *Epidermis*, a single layer of cells. Many of the cells undergo modifications to form gland cells and receptor cells. (*c*) *Muscle layers*, a thick non-segmented, smooth circular muscle layer is followed by longitudinal and oblique layers of muscles. The locomotor structures remain embedded in the muscle layer. (*d*) *Peritoneum*, a single layer of cells forming the inner border of the body wall.

DIGESTIVE SYSTEM

The members of the Phylum Annelida exhibit various feeding devices (Fig. 15.46). Most polychaetes feed on small animals. *Aphrodite*, *Nereis* and *Eunice* live on worms, small crustacea and molluscs. In aquarium observations a few species of *Nereis* have been found to be omnivorous. *Phyllodoce* is provided with an unarmed proboscis for feeding. *Neanthes brandti* and many others feed on pieces of green algae. Filter feeders like *Sabella* and *Serpula* feed on small planktons with the help of their tentacles. Substrate feeders feed by swallowing mud or fine sand. *Chaetopterus* secretes a glandular secretion which makes a mucous net. The net filters out plankton as well as suspended organic matter. *Arenicola* makes a 'L'-shaped burrow and rests in the horizontal part. It everts the proboscis through the vertical part. It feeds five to eight hours a day.

In feeding, the buccal cavity armed with teeth and jaws is everted. In many polychaetes the tentacles are extended on the sand in search of dead animals. Each tentacle is provided with a ventrally-placed ciliated groove. The dead animals are carried to the mouth through these grooves. Little information is available about the digestion in polychaetes.

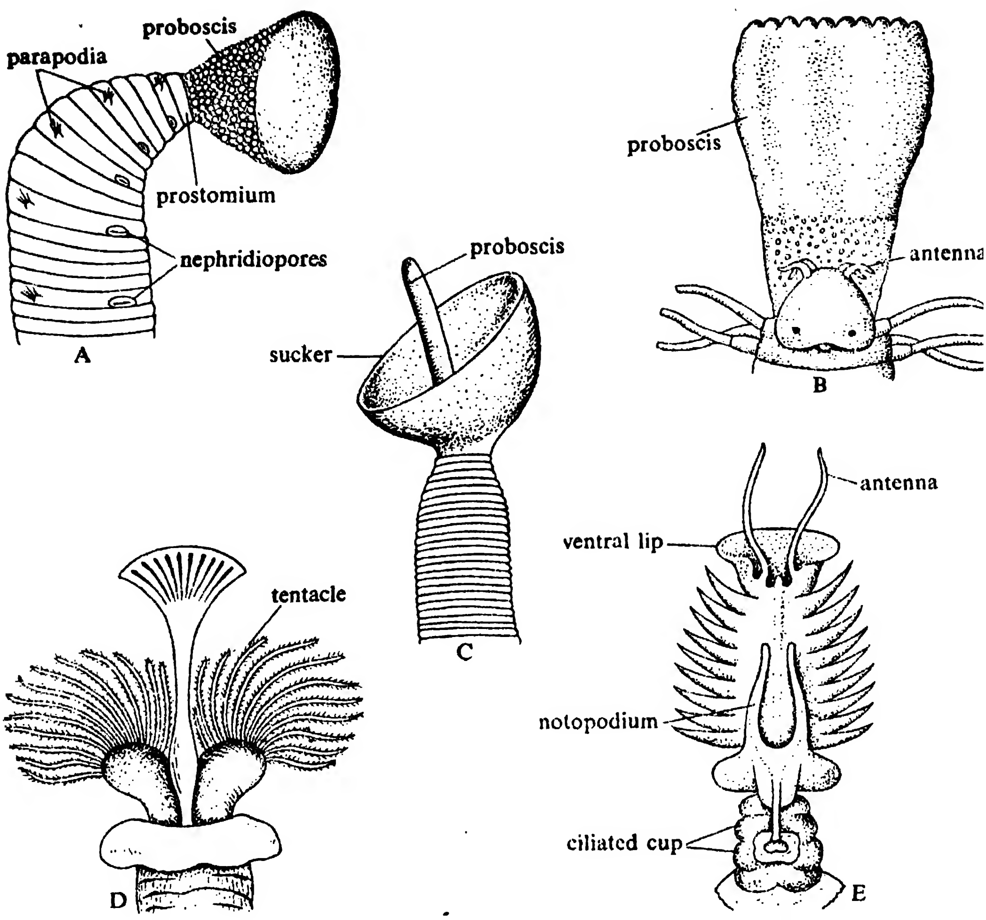


Fig. 15.46. Feeding devices in some annelids (after various sources). A. *Arenicola*. B. *Phyllodoce*. C. *Piscicola*. D. *Serpulla*. E. *Chaetopterus*.

Most oligochaetes feed on dead plant parts, micro-organisms and larvae or eggs of insects embedded in the mud and a few feed on decaying meat. Oligochaete, like *Chaetogaster* crawls among plants and swallows *Stentor*. In most oligochaetes the upper and lower floors of the pharynx are used during feeding.

Detailed information about the mode of digestion in many oligochaetes specially *Lumbricus* is at hand. In *Lumbricus* digestion starts in the pharynx where enzymes are secreted. Proteolysis occurs in the gut up to segment 60. There are two types of protein splitting enzymes of which one has an effective pH range of 5·2 to 5·7 while in the other the pH range is 7·7–8·3. These enzymes and lipase work between segments 20–60. After 60th segment, up to certain length the gut is alkaline. In oesophagus there are calciferous glands. These glands are rich with carbonic anhydrase and they release calcium carbonate to neutralise the acid soil of the intestine. The chloragogen cells store lipid and synthesise glycogen. These are used during starvation.

About seventy-five per cent of leeches are ectoparasites on vertebrates. *Rhynchobdella* and *Placobdella* pierce the integument of the prey with the help of their proboscis. *Pisciocola* makes searching movements before attaching itself to fishes. *Gnathobdella* extend their jaws and a synchronous sewing machine like motion of the jaws are made to make perforations on the skin. *Hirudin* secreted during bite prevents clotting of blood. The process of digestion in *Hirudo* is interesting. In a full-fed leech the caeca become distended with blood. Within 10 days after the meal about 40% of the watery content of blood is removed

by the nephridia and the ingested blood becomes concentrated. Process of digestion is usually very slow and undigested erythrocytes have been encountered in *Hirudo* one and half years after feeding. The digestion of blood and its preservation are carried on mainly by symbiotic and a kind of bacteria *Pseudomonas hirudinis*. In the cells of the stomach glycogen is found.

LOCOMOTION

Locomotion in Annelids are carried by three agents: (a) Locomotor structures, (b) body musculatures and (c) hydrostatic skeleton. In different annelidan species, locomotion is not caused by any individual locomotory agent, but it is the resultant outcome of a coordinated effort of all those three agencies.

Locomotor structures

Parapodia. Most polychaetes move about by the *parapodia*. By the action of the segmentally arranged parapodia they paddle through water. During paddling two parapodia of a segment always remain in an opposite phase of motion. Parapodia are hollow segmentally arranged lateral extensions of the body, typically divided into dorsal *notopodium* and ventral *neuropodium*. Each lobe carries a bundle of bristles strengthened by supporting *aciculum*. The point of attachment of the parapodia with the body wall acts as a hinge for forward and backward movement. The coelomic cavity extends into parapodia and the hydrostatic pressure is exerted by the coelomic fluid. Two sets of oblique muscles, originating from the midventral line of the body wall are attached to the parapodia dorsally and ventrally. In addition to these muscles, there are intrinsic protractor and retractor muscles that are responsible for protrusion and withdrawal of bristles and the supporting acicula.

The parapodia become variously modified in different polychaetes (Fig. 15.47). The modifications are correlated with different functions. There are well-developed and modified into creeping

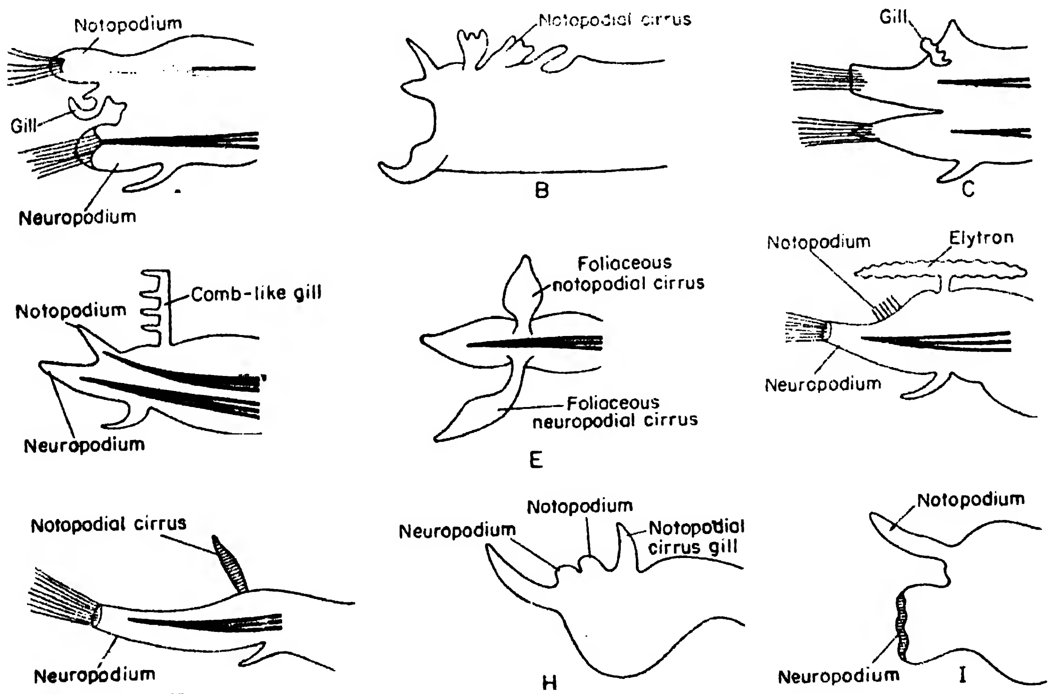


Fig. 15.47. Showing the modification of parapodia in different annelids. A. Parapodium of *Nepthys*. The notopodium gives a curved gill on its under side. B. Parapodium of *Amphinome*. The notopodium is indistinct. C. Parapodium of *Glycera*. D. Parapodium of *Eunice*. It is uniramous with reduced notopodium. The notopodial cirrus acts as the comb-like gill. E. Parapodium of *Phyllodoce*. The cirri are foliaceous. F. Parapodium of *Polynoe*. The notopodium is not developed. An elytron is present. G. Parapodium of *Syllis*. Notopodium is entirely absent. H. Parapodium of *Scoloplos*. Both the neuropodium and notopodium are reduced. I. Parapodium of *Sebella*. Cirri are absent.

and swimming types. In these forms the parapodia are restricted on some anteriormost segments as head crown and are poorly developed or absent in the rest of the body segments. In sand or mud burrowers and tube-dwellers the parapodia are poorly developed or absent especially those of the posterior part of the body.

Setae. In oligochaetes locomotion is caused by the setae which are implanted directly in the body muscles and are mostly oriented in the ventral region of the body segments. The setae are of various types (Fig. 15.48). They might be long or short, straight or curved, simple or forked, pectinate or plumose type. In general, the longer plumose or forked setae are the characteristic features of the aquatic swimming species. In burrowing species, the setae are short, straight, simple and blunt. The setae are embedded in and are developed from *setal sac*. The extension and withdrawal of the setae during movement are caused by a pair of setal muscles and the associated circular muscles.

Suckers. The parapodia and setae are absent in Hirudinea. Anchorage on the substratum during locomotion is caused by two suckers, one is situated at the anterior (Anterior sucker) end and the other is located at the posterior end (Posterior sucker) of the body. The suckers are formed by the fusion of several body segments and they play their role alternately as adhesive organs. Adhesion with the substratum during locomotion is possible for the presence of specialised epidermal *sucker glands* situated in masses in the anterior and posterior suckers.

A general survey of the locomotor structures will reveal that there is a gradual tendency towards the loss of well-formed locomotor structures in course of evolution. The loss of distinct locomotor structures is compensated by the development of body musculature.

Body musculature

Three major sets of muscles, viz. *longitudinal muscles*, *circular muscles* and *oblique muscles* help in locomotion. In polychaetes

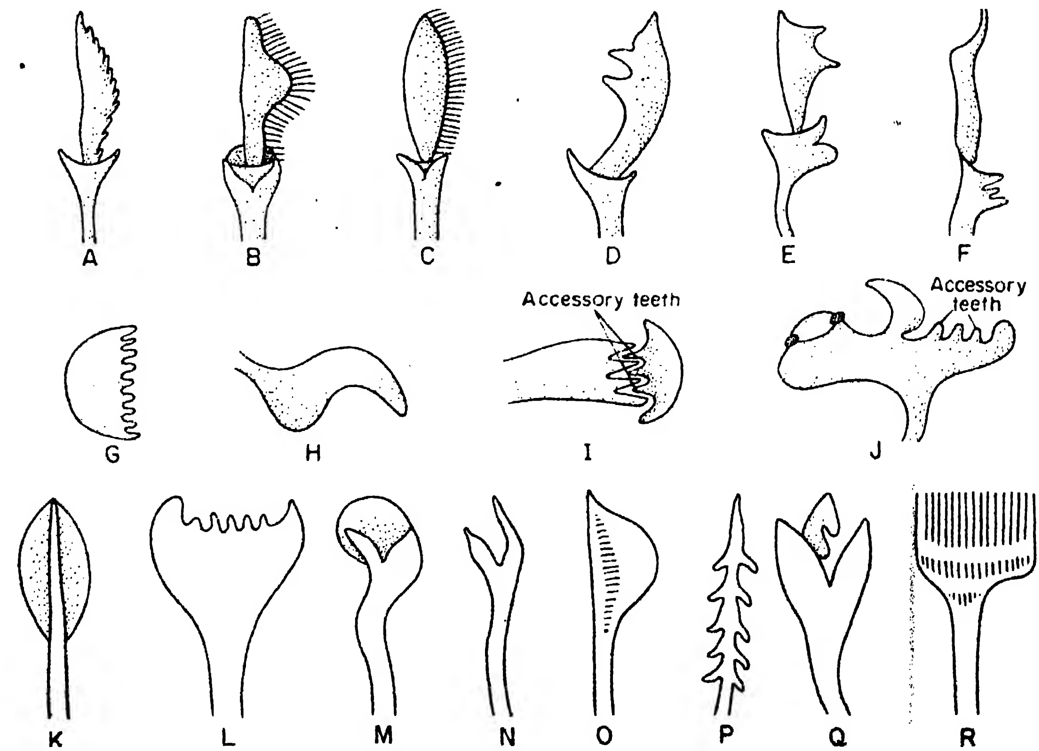


Fig. 15.48. Setae of various annelids: Jointed forms: *Nereis* (A, B), Heteronereis stage (C), *Eunice* (D), *Syllid* (E), *Phyllodoce* (F). Uncini forms: Serpulid (G), Sebellid (H), Terebellid (I–J). Simple forms: Terebellid (K), Maldamid (L), Polydea (M), *Euphosyne* (N), *Polynoe* (O), *Hermione* (P, Q), *Eunice* (R). The setae may be notched (L) or hooked (M–N) or serrated (O) or comb-like (R).

these three types of muscles are less developed. The *longitudinal muscles* do not form a continuous layer, instead they are broken up into two paired blocks, one is dorsal and the other is ventral. The *circular muscles* are thin and feebly developed. They are oriented outside the longitudinal muscle bands. The *oblique muscles* are present as two thin strands in each segment and are connected between circular muscles of dorsal and ventral sides. The function of these muscles is antagonistic in nature and causes waves of contraction along the body. The oblique muscles and parapodial muscles are interpolated in each segment from the long muscles along its body length, creating retardation of contraction and expansion of body in lengthwise. In oligochaetes, the body wall is composed of a continuous layer of longitudinal muscles on the inner side and circular muscles on the outerside. These muscles are so arranged that they can exert considerable pressure upon the coelomic fluid which they surround. The muscle fibres of the longitudinal muscles are considerably long extending 2–3 segments. As a consequence the body segments are linked into small groups. Each segment has its own segmental nerves which control the localised muscular contraction under the central nervous system. The longitudinal muscles are divided into seven blocks, each is encircled by a sheath of connective tissue. The oblique muscles, connecting the dorsal and ventral circular muscles, are better developed and help in contraction and extension of localised body segment. The activity of oblique muscle is correlated with that of longitudinal and circular muscles. Besides, the intrinsic muscle fibres in the transverse septa separating the coelomic cavity help to resist the stress caused due to change of pressure in the coelomic fluid. The continuity of the coelomic fluid in different body segment is caused through a foramen present in each transverse septum in the ventral nerve cord region. These foramina are provided with sphincter muscle. Greatest development of body musculature is encountered in Hirudinaria. They have well-formed circular, longitudinal and oblique muscles. Between the outer circular and inner longitudinal muscles, a double layer of oblique muscles is present. The oblique muscles co-ordinate the activity of the circular and longitudinal muscles. When the body of a leech becomes long, the oblique muscles reinforce the action of the longitudinal muscles to make it short. When the body of leech becomes short, they reinforce the action of the circular muscles, thus causing elongation. At places the oblique muscles are so oriented that they offer rigidity of the body by enhancing the hydrostatic pressure. This action enables leech to sit upright on its posterior suckers. The existence of *dorsoventral muscles* in leech is significant, because these muscles make the body of the leech flat and ribbon-like and also increase the efficiency of dorsoventral undulations of the body during swimming.

Hydrostatic skeleton

In annelids, the coelom appears to play an important role in locomotion. The coelom in annelids, filled with incompressible coelomic fluid, acts a hydrostatic skeleton. It is enclosed by the muscles of the body wall. The importance of hydrostatic skeleton in locomotion of annelids has been emphasised by Chapman and Newell. Transmission of coelomic fluid from one coelomic compartment to another during localised muscular contraction depends greatly on the nature and disposition of transverse septa. The body of an annelid is a cylinder, the wall is made up of muscles and the lumen is filled with coelomic fluid. A cylinder encircled by circular muscles only, when contract towards one end, will cause diminution of the diameter at that end thus resulting in movement of coelomic fluid. The movement of coelomic fluid may cause: (i) Increase in length of the contracting end of the body (the other end to remain unaltered), (ii) Increase the diameter of the other end (total length remaining the same), (iii) increase in the length of the other end (the diameter remaining unchanged) and (iv) elongation of both ends of the body. But the existence of longitudinal muscles and their contraction in conjunction with regional hydrostatic or coelomic fluid pressure help in restoration of the cylinder to its original state.

Hydrostatic Skeleton in Polychaetes: The hydrostatic skeleton is less developed in Polychaetes. The coelom is spacious with ill-developed muscular layers and is divided into compartments by

transverse septa. The perforations in the septa permit transfer of coelomic fluid from one compartment to another. In this group of annelids the circular muscles are feebly developed and are interrupted laterally by the parapodial muscles.

Hydrostatic Skeleton in Oligochaetes: The body forms a complete cylinder with well-developed circular and longitudinal muscles and uniformly developed transverse septa. The hydrostatic skeleton is well-organised and it actively participate in the various modes of locomotion encountered in oligochaetes. The transverse septa regulate the changes of pressure and limit them to particular regions of the body. The septa control the pressure of the fluid through the ventral foramen. The increase of pressure in the coelomic fluid of a segment is substantially isolated from adjoining segments.

Hydrostatic Skeleton in Hirudinia: Due to overdevelopment of body musculature and obliteration of coelom by the thick muscular coat and botryoidal tissue the coelomic spaces become greatly reduced. Reduction of coelom results in the increase of hydrostatic pressure and renders rigidity to the body. As a consequence the hydrostatic skeleton is highest developed in hirudinia amongst the annelids.

Mechanism of Locomotion

Four types of movement are observed in Polychaetes. They are: (i) *Slow crawling:* this type of movement is caused by the paddle-like action of parapodia. (ii) *Rapid crawling:* this serpentine movement is caused by the co-ordinated action of the longitudinal muscles and the parapodia. (iii) *Peristaltic motion:* This type of movement is best seen in *Arenicola*. The movement is resulted from the anterior to the posterior passage of swollen transverse bands. Swelling is caused by the local relaxation of the body wall where the turgor of the coelomic fluid plays an important role. (iv) *Swimming:* This type of movement is resulted by the paddling of parapodia accompanied by the horizontal serpentine movement. Most of the pelagic and benthic forms swim for the purpose of food-collection and reproduction.

The oligochaetes move by either crawling or by digging. Crawling is effected by the peristalsis of the body by the action of the circular and longitudinal muscles and the coelomic fluid too. The peristaltic motion is initiated by the ventral ganglion in each segment and the rythmic co-ordination depends entirely upon the excitation of the ventral ganglion. In oligochaetes co-ordination between nerve ganglia and muscles is significant. Digging is done by the forward extension of the anterior segments into the spaces between the soil particles. The coelomic pressure is raised to widen the space and to pull the posterior end.

The crawling of oligochaetes is performed by alternate expansion and contraction of the body musculature. The setae at two different places in the body anchor on the soil and the portion in between extends forward with setae of that region pulled. In *Lumbricus* the contraction of circular muscles causes the withdrawal of setae and consecutively, relaxs the longitudinal muscles of all segments or metameres up to its middle starting with the first. Aquatic *Aelosoma* crawls with the ventral cilia of the head lobe.

Leeches move by crawling on a solid substratum and by swimming. Leeches crawl by exhibiting looping movements. *Hirudo* first attaches itself on the substratum with the help of posterior sucker and then extend the body by the action of the body musculature and hydrostatic skeleton to the oral disc. It then bends its body like an inverted 'U' and drags the posterior sucker just behind the region of attachment. The rate of looping movement depends upon the extrinsic factors, especially the temperature. Most leeches can swim quite effectively in water by causing dorsoventral serpentine movement. *Branchiobdella* moves with mouth and sucker.

CIRCULATORY SYSTEM

The circulatory system is closed type and consists of blood vessels through which blood is distributed and collected from different parts of the body. The colour of blood is red due to the presence of haemoglobin which remains dissolved in the plasma. In all oligochaetes haemoglobin is present. As a result of reduction of blood vessels in many polychaetes like *Aphrodite* and *Phyllodoce*, haemoglobin is absent in the blood but haemoglobin-containing cells are found in the coelomic fluid. Sabellids and Serpulids have green chlorocruorin and haemerythrin is present in

Magelona. The dorsal vessels in polychaetes show peristaltic waves and blood flows in it from the posterior to the anterior direction. The ventral vessel cannot contract while lateral vessels pulsate. A true blood-vascular system with close vessels and their ramification is present in the Acanthobdellida and the Rhynchobdellida. But haemoglobin is usually absent in them. The ground plan of blood vessels inside the body consists of dorsal, ventral and lateral vessels. These vessels are interconnected with each other through segmental loops or ring vessels.

In oligochaetes, the dorsal vessel, with its valves, functions as heart. The dorsal vessel collects blood from the vascular areas of the intestine and drives it towards the anterior end. From the dorsal vessel arises in each segment a pair of ring vessels which pass to the subneural vessel running beneath the ventral nerve cord. In the anterior end of the body one or more of these ring vessels become muscular, contain valves and pulsate rhythmically. These modified ring vessels are called lateral hearts. The lateral hearts drive blood towards the ventral vessels. In the ventral vessel blood flows from anterior to the posterior region. The ring vessels and the ventral vessel supply blood to the individual organs of the body. In larger forms of oligochaetes additional vessels like subintestinal or supra-intestinal vessel are often present. In an active lumbricoid the blood pressure is about 10 mm of mercury.

In Hirudinea, the dorsal vessel conveys blood anteriorly and the ventral vessel conducts blood towards posterior region. The dorsal and ventral median vessels lie in longitudinal coelomic channels and are connected with each other at the end of the body through loops. Many minute vessels that arise from the vessels, anastomose beneath the integument and organs. These anastomosing branches remain surrounded by botryoidal tissue in *Hirudo.*

Presence of glucose, amino-acids and lipids in blood of *Pheretima* has been demonstrated very recently. This observation indicates very conclusively that blood in this animal is a medium which transports nutrients to the tissues.

RESPIRATORY SYSTEM

Usually the entire surface of the skin is used in respiration of annelids, but there exists specialised respiratory structures in many annelids (Fig. 15.49). In many Polychaetes there are highly vascularised gills attached to the notopodium as in Glycera, Eunice and Nepthys. In Arenicola the gills are red in colour. Some consider the tentacles of Sabellids and Serpulids as respiratory structures. In *Galeolaria* (a Serpulid) the branchiae are located anteriorly. They are branched and associated with an operculum.

In Nereis amongst the polychaetes the parapodia and their adjoining areas are highly vascularised, oxygen enters the body through diffusion. It has been estimated that the O_2 capacity is 11·5 cm³ for 100 cm³ of blood in this species. In resting condition the O_2 uptake is slowed down in Nereis.

Larger forms of oligochaetes have richly vascularised epidermis. In aquatic forms various types of respiratory organs are seen. Elongated appendages in the anal region of *Dero* serve as respiratory structures. In *Branchiura* the last 40 segments are provided with thread-like, blood-filled evaginations. The members of the family Tubificidae use hind gut as respiratory surface.

In Hirudinea the thick network of coelomic capillary channels between the epidermal cells helps in respiration. But many Pisicolidae have special respiratory structures. These are vascularised evaginations having connections with coelomic channels. Similar evaginations in *Ozobranchus* are lamellated. Hirudo and Haemopsis can respire both on land and in water.

EXCRETORY SYSTEM

In general, the excretory system consists of paired lobes called *nephridia* which are metamerically arranged. These nephridia are open at both ends and form a sort of tunnel between body cavity, coelom or blood sinuses and outside. The inner aperture lies in the coelom and the outer aperture is situated in the integument.

A typical nephridium consists of a *nephrostome* or a funnel which hangs into the coelom and leads to the *nephridial* duct. The nephridial duct may be long, short, coiled or modified otherwise. The duct is ciliated internally and is accompanied by blood vessels. Each nephridium is derived from a single cell called *nephroblast.* The nephridia are ectodermal in

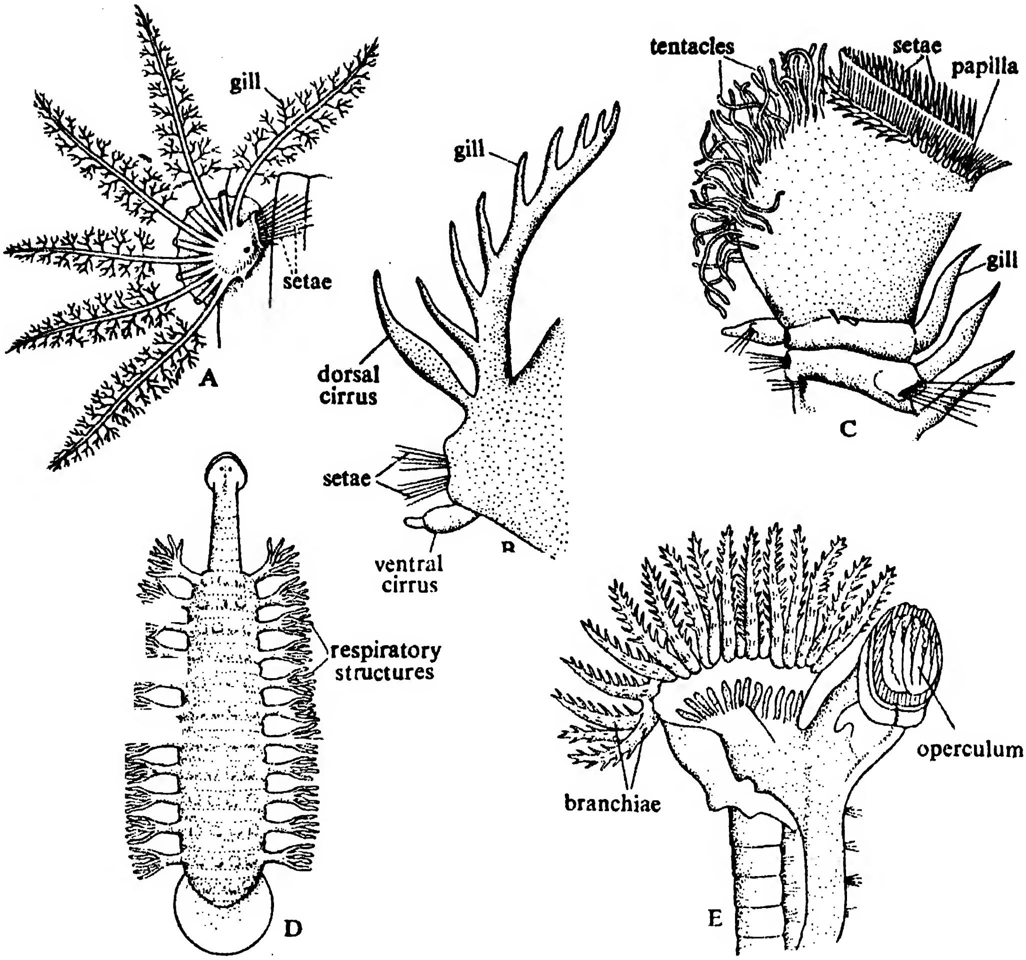


Fig. 15.49. Respiratory structures in a few annelids (after various sources). A. *Arenicola*. B. *Eunice*. C. *Sabella*. D. *Ozobranchus*. E. *Galeolaria*.

origin. In following up the developmental stages of nephridium of annelida two types of nephridial systems are encountered (Fig. 15.50). They are (*a*) provisional or embryonic nephridia and (*b*) the permanent nephridia. Embryonic nephridia are temporary structures and disappear as soon as permanent nephridia start developing. Embryonic nephridia develop both in the head segments and in the trunk segments. Embryonic head nephridia are found in many polychaetes and oligochaetes. They are branched in *Echiurus* and *Polygordius*. Embryonic trunk nephridia are strictly segmentally arranged and may persist in those forms where permanent nephridia do not develop. Five such pairs of nephridia persist in Nereis. In most oligochaetes permanent nephridia are absent in some of the anterior segments. The same is true for many polychaetes and hirudinea. It is probable that provisional nephridia were present in the larval stage and subsequently permanent nephridial development never occurred there. Thus the absence of permanent nephridia in the anterior segments may be explained.

Structurally embryonic nephridium is similar to those of permanent nephridium. But in *Glycera* and *Phyllodoce* the inner aperture and in hirudinea both inner and outer apertures are absent.

Depending upon the size and number present in a segment the nephridia are divided into two types: (*a*) Meganephridia or Holonephridia and (*b*) Micronephridia or Meronephridia. The micronephridia are very minute and are numerous in a segment while the meganephridia are

larger in size and in a given segment there occur only one pair. All the nephridia in Pheretima are of micronephric type.

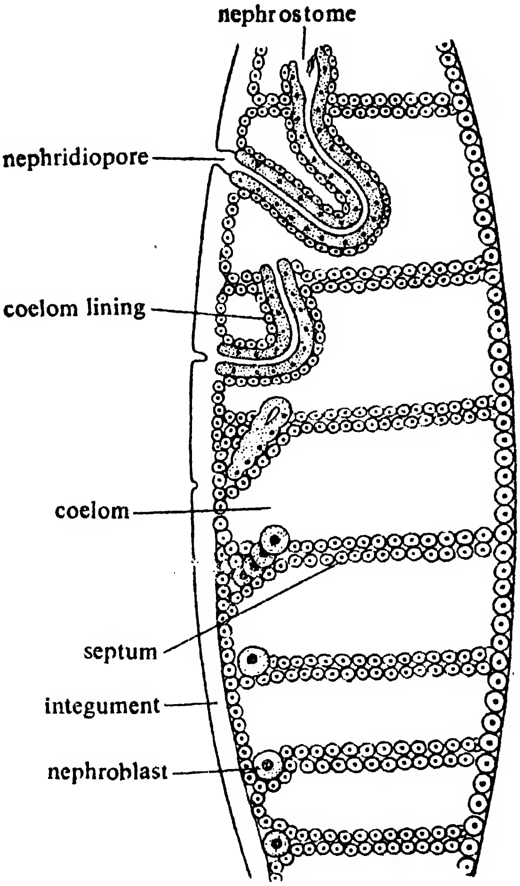


Fig. 15.50. Development of metanephridia in annelids (after Kaestner).

The nephridia of Lumbricus, Chaetogaster and Nereis are meganephric. It is believed that the micronephridia are nothing but broken or disintegrated meganephridia. In *Megascolecidae* both micronephridia and meganephridia are present even in the same segment. In *Serpula* meganephridia are present in the anterior segments while micronephridia occur in the posterior segments.

Permanent Nephridia in different classes

Chaetopoda : In most polychaetes metanephridia are present. A typical metanephridium consists of the following: (*a*) An inner ciliated aperture opening into the body cavity or coelom and is called *nephrostome*. (*b*) A canal or coiled tube connected to the nephrostome. The canal is dilated internally and sometimes its internal wall is glandular. (*c*) A terminal end which usually terminates in a laterally placed aperture, called *nephridiopore*.

In Errantia each segment has a pair of nephridia. *Arenicola* is provided only with six pairs. In Capitellidae there may be one to six pairs of permanent nephridia in each of the trunk segments. In Terebellidae there are one to three pairs of nephridia in the thorax. Sabellidae and Serpulidae have one pair in the thorax. But in all these families numerous nephridia occur in the posterior segments. Numerous nephridia are housed in Earthworm. The wide funnels and short ducts of these nephridia suggest that they serve as gonoducts in some forms. In many polychaetes like *Phyllodoce* segmentally arranged ciliated funnels called *coelomoducts* are present (Fig. 15.51). These ducts rarely open to the outside and often coalesce partially or completely with the nephridia and thus the function of excretory and reproductive ducts combine in one set of segmental organ.

Some families like Phyllodocidae and Glyceridae have *protonephridia* in place of metanephridia. In protonephridia, the ciliated coelomic aperture is absent. The tubes thus open blindly in the coelom and are branched. Separate or groups of specially modified cells called *solenocytes* remain attached to the blind end of the tubes. Each solenocyte is a round cell with a slender tubular projection which anchors on the blind tube. Electron micrographs show that the long tube consists of a membrane with more than 15 longitudinal ridges or rods and internally carries an unusually long flagellum to drive the internally accumulated fluid (Fig. 15.52).

Oligochaetes : In oligochaetes metanephridia are usually present in all segments excepting a few anterior segments. A metanephridium differs from a protonephridium in having a ciliated funnel or nephrostome. In aquatic forms reproductive segments lack nephridia. As a rule there is one pair of nephridia in each segment but in *Brachidrilus*, there are two pairs, in *Trinephros*, there are three pairs and there are four pairs in *Acanthoarilus* in each segment. In tropical Megascolecidae, the nephridial

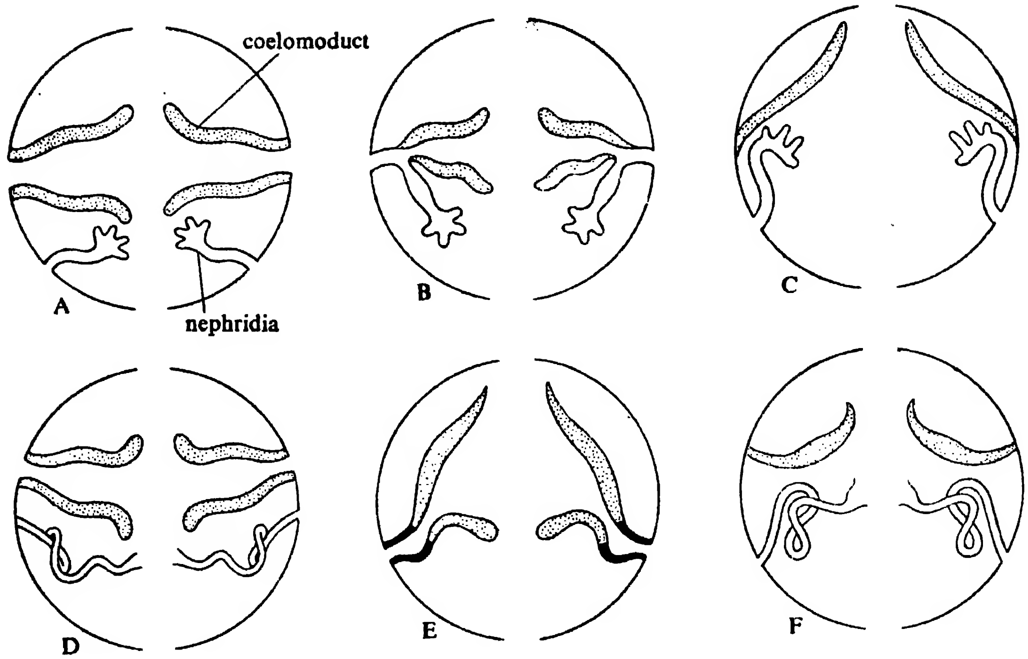


Fig. 15.51. Relationship of nephridia and coelomoducts in polychaeta (after Parker and Haswell). A. Hypothetical stage (Nephridia closed and coelomoducts separate). B. In Phyllodocidae (Nephridia closed but united with coelomoduct). C. In Nephthyidae (Coelomoduct reduced as ciliated organ). D. In *Dasybranchus* (Coelomoduct separate from nephridia with nephrostomes). E. In most annelids (Nephridia with nephrostomes united with coelomoducts to form segmental organ). F. In *Nereis* (Nephridia with nephrostomes and separate coelomoducts reduced as ciliated organ).

primordia in each segment splits and as a result numerous nephridia occur in each segment. These nephridia are called diffused or *plectonephric nephridia*. In the tropical *Phretima posthuma* many nephridia open into the pharynx (Peptonephric) and in the alimentary canal (Enteronephric). This is a device for the reabsorption of water.

Hirudinaria : In Hirudinaria the permanent nephridium is lacking in many anterior and posterior segments. The metanephridium consists of a ciliated nephrostome or funnel that leads into an ampulla filled with amoebocytes and closed off against a nephridial duct. Besides the nephrostome all parts of the nephridium are formed by a close set of gland cell traversed by intracellular spaces or ducts. The nephrostome may start from the coelomic spaces, from ventral median channel (*Glossiphonia*), from contractile spherical enlargement or ampullae (*Haemopis*) or from blood sinuses in which the testes lie (*Hirudo*).

In *Pontobdella* distinct nephridium is absent and its place is taken up by a complex network situated on the ventral side of the body.

The anal tubes in Echiuroidea are considered as excretory structures. The nephridia act as osmoregulatory organs specially in fresh water forms.

Nephromyxia. In many polychaetes the association between the coelomoduct and nephridium makes an interesting study. Instead of remaining separate they show total or partial fusion and form a dual segmental organ called nephromyxia. As the nephridium is ectodermal in origin and the coelomoduct is mesodermal in origin a nephromixium is formed by the participation of both ectoderm and mesoderm. The nephromixium performs two functions. In one hand, it serves the function of excretion and on the other hand it also serves as a passage for the exit of gametes. In some cases they share the same external opening but when the association between them becomes very close they often share the same duct.

The combinations of the coelomoduct

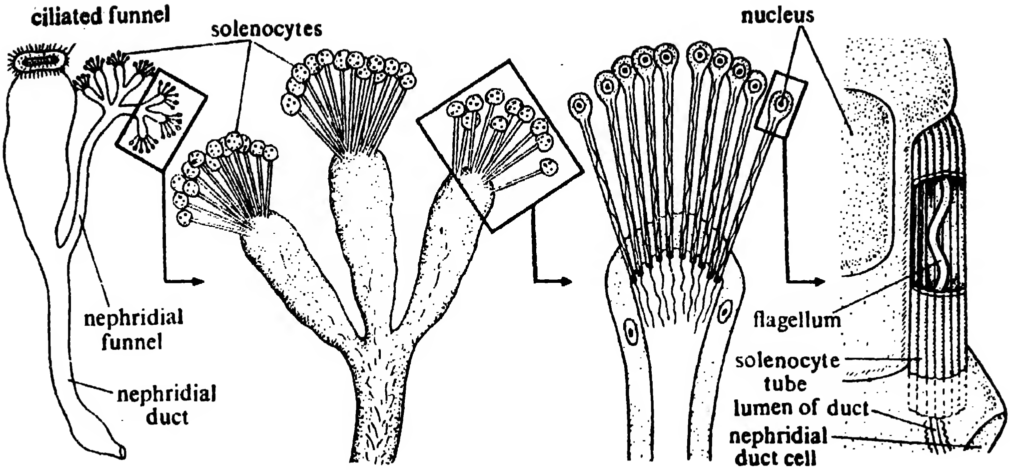


Fig. 15.52. Structure of excretory apparatus in annelid (after various sources).

and the nephridium are of the following types:

(*a*) **Protonephromyxium.** In this case the coelomoduct becomes united to a protonephridium. Both reproductive and excretory products are conveyed to the exterior by it. Protonephromyxia condition occurs in *Phyllodoce*.

(*b*) **Metanephromyxium.** In this case the coelomoduct becomes united to a metanephridium as in *Hesione*.

(*c*) **Mixonephridium.** In this case complete fusion between the coelomoduct and the nephridium results in the formation of a simple funnel-like organ only. Mixonephridia condition is most prominent in *Arenicola*.

(*d*) **Ciliated organs.** The coelomoducts alone become very much reduced in some case and give rise to ciliated organs which do not open to outside. In Nereis such ciliated organs are found and they remain attached to the dorso-lateral longitudinal muscles.

REPRODUCTIVE SYSTEM

Asexual. Amongst the annelids asexual reproduction is encountered in many polychaetes. In forms, like *Filigrana* and *Salmacina*, transverse fission occurs near the posterior end of the body dividing the animals into two unequal parts. The anterior part of the half regenerates a new pygidium and the posterior half regenerates new cephalic regions. The sexes of the two individuals produced by such fission are always identical. That means metagenesis or alternation of generation is lacking. In some forms like *Syllis hyalina* a constriction occurs somewhere in the middle of the body. The constriction deepens and ultimately two individuals are formed. The anterior half with the original head behaves like a non-sexual part and regenerates anal region. While the posterior half develops a new head and becomes an independent male or female individual. That means metagenesis or alternation of generation is eminent in this case because sexual worms are being formed out of non-sexual worms. In *Autolytus* and *Myrianida* a zone of proliferation exists between the anterior non-sexual part and posterior sexual part. This zone gives rise to a series of zooids which remain arranged in a linear fashion. The posteriormost zooid in the chain is oldest and most developed. The sexes of the individuals in the chain are always identical. *Syllis ramosa* lives a sedentary life inside the canal system of some deep sea sponges. In this type some of the parapodia become transformed into buds which grow laterally and form a colony. Some branches from the bud develop parapodia, head and gonad and ultimately leave the parent body to form sexual individuals. In *Trypanosyllis* buds come out from the under surface of last two segments.

Asexual reproduction is not very common in oligochaetes and Hirudinea.

Sexual. Most polychaetes are dioecious, but sexual dimorphism is seldom encountered. Well-formed gonads occur only in few polychaetes. The reproductive

cells mature in clumps on the walls of the coelom and it is believed that they arise from specially determined cells and not from coelomic epithelium. These clumps form gonads during reproductive season. Gonads may occur in most segments or they may remain limited in some posterior segments. On maturity, the peritonium covering the gonads bursts and sperms or ova, as the case may be, are liberated into the coelomic fluid. Finally the sperm or ova come to the outside of the body through body wall or through ducts. Often nephridial ducts become transformed temporarily into genital ducts to liberate the reproductive cells outside. In *Phyllodoce*, genital funnels appear and get connection with the nephridia only when the gonads become mature. Fertilization is external but in some forms copulation may occur as the females of these species are provided with receptacles.

All oligochaetes are hermaphrodite and have well-defined gonads which remain limited to few segments only. Testes are one to four pairs and lie in adjacent segments.

The testes remain encased in special sacs called seminal vesicles. Male reproductive cells are detached early from the testes and they are nourished in these vesicles. The sperm ducts bear funnels at their tips and traverse several segments posteriorly, before opening to the outside through the gonopore. Ovaries are strictly one pair and are located posterior to the testes bearing segments. Each ovary is followed by an oviduct and the two oviducts unite before opening to the outside through gonopore. Though hermaphrodite, the oligochaetes practise cross-fertilization. Reciprocal copulation enables the worm to pass on sperms of one worm to the other. The sperms thus received remain stored in spermatheca.

Hirudinea, like the oligochaetes, are hermaphrodite. Female reproductive organs consist of several rows of reproductive cells encased in a pair of ovarian tubes. The ovarian tubes are short in *Gnathobdella*, long in *Rhyncobdella* and looped in *Pharyngobdella*. The anterior end of the tube is prolonged as oviduct. The two oviducts often fuse to form a vagina which opens to the outside in the 11th segment.

Male reproductive system consists of 4–17 pairs of metamerically arranged testis sacs. There is a pair of longitudinal ducts called vas deferens. The vas deferens widens at the tip to form the seminal vesicle. Each seminal vesicle opens into a median atrium. The atrium opens to the outside through the 11th segment. The atrium often remains provided with an intromittent organ called penis.

NERVOUS SYSTEM

The nervous system, at least during development, exhibits a segmented condition that is, its segmentation corresponds to the segmentation of the mesoderm. Each segment carries a pair of ganglia on parallel cords and remains connected by commissures and thus gives a ladder-like appearance. As development proceeds there occurs fusion of ganglia, the nerve cord and commissures. Fusion of anterior segments in many forms results the formation of a subpharyngeal ganglion or ganglia. From the apical sense organ of the trochophore arises the supra-oesophageal ganglion or the brain. The supra- and subpharyngeal ganglia remain connected with each other through the circum-oesophageal connectives.

REGENERATION

In many polychaetes there is remarkable property of regeneration. In *Autolytus pictus* any one of the segments between first and seventh can regenerate head and anterior segments after removal. When the segments from 8 to 13 are excised only 4 segments with parapodia and the head will be formed. When cut behind 14-segment only one segment with setae will develop. Only the head is formed from the posterior end.

The regeneration faculty is also prevalent in soil oligochaetes.

PHYLOGENETIC RELATIONSHIP

The archiannelids were regarded to be the most primitive members amongst the annelids. But recently the archiannelids are regarded to be the aberrant members of other annelidan families. This idea has made the phylogenetic concept complicated. The members of Polychaeta are regarded to be ancestral forms of all annelids because they possess the undernoted features: (i) Marine and dioecious, (ii) serially repeated unspecialised reproductive units, (iii) numerous minute eggs, (iv) external fertilization, (v) pelagic

larval stage, (vi) primitive organisation of the nephridia. But Clark (1969) considered the oligochaetes to be most primitive, because they resemble the proto-annelids in many features, especially in the segmental organisation of the musculature and the compartmentalisation of coelom by intersegmental septa and ventral and dorsal mesenteries. The specialisations encountered in the reproductive and excretory. systems in oligochaetes are directly related to their terrestrial and fresh-water mode of living. The locomotory behaviour of the oligochaetes resembles closely that which might be expected of the proto-annelidan form.

SUMMARY

1. Annelids are widely distributed triploblastic animals. There exists a great diversity in form and structures of annelids.

2. Most of the members of this phylum are with cylindrical and elongated bodies. The body is made up of segments, (metameres) or annuli arranged in an antero-posterior axis. In many forms a partition called septum is present between two successive segments.

3. Body cavity is a true coelom in annelids.

4. Well-formed organs are present for performing different body functions.

5. A system of closed blood vessel is present in earthworm but in many forms the blood vascular system is a mixed type.

6. Alimentary system is well-developed.

7. Excretory system is represented by nephridia which are often metamerically arranged.

8. Nervous system is represented by a nerve ring round the oesophagus and a ventral ganglionated nerve cord.

9. Reproductive organs are well-formed.

10. The phylum is divided into three main classes—Chaetopoda, Hirudinea and Archiannelida. Earthworm, Leech, Nereis are the familiar examples.

CHAPTER 16

Phylum Arthropoda

This phylum includes the largest number of animals (Fig. 16.1). Nearly 900,000 species are known to mankind. In the course of evolution, the arthropods appeared much earlier and were the first to dominate the land. The most interesting feature of this group is that most of the members have undergone very little change during their evolutionary history. Thus they bear close similarity with their ancestors. These animals have explored all possible habitats and are seen from snow covered mountain peaks to the depth of the ocean. Many members of this phylum are closely related with different aspects of human life like food, health, etc., and thus have great economic importance.

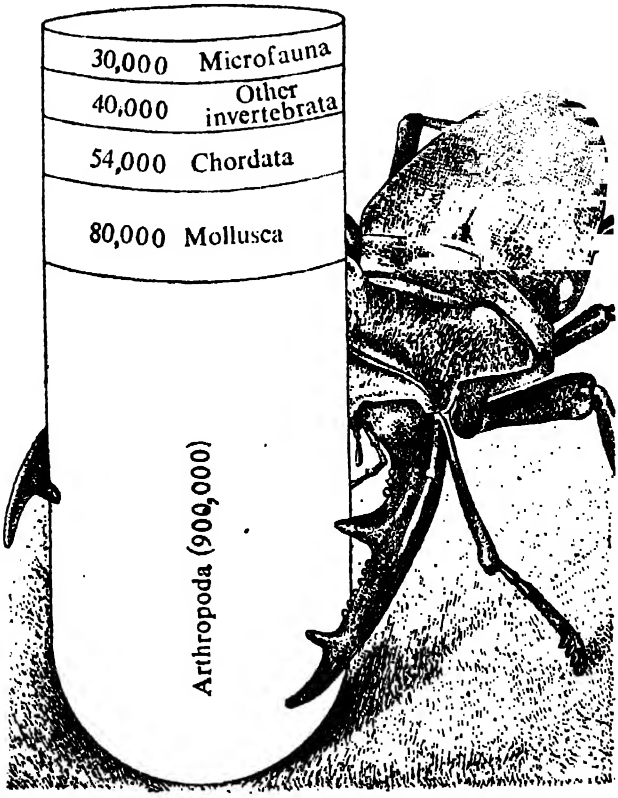


Fig. 16.1. In the animal world, the Phylum Arthropoda includes the largest number of species. All of them possess metameric segmentation, hard chitinous exoskeleton and jointed legs. Number shown against each group denotes the approximate number of species.

IMPORTANT FEATURES

1. Body is *metamerically segmented* and is with perfect *bilateral symmetry*. 2. Anterior segments are specialised to form a distinct *head*. 3. A pair of externally jointed *appendages* is usually present in each segment. 4. Body is externally covered with non-living chitinised *exoskeleton*—usually composed of carbohydrate and protein. 5. A process called *moulting* or *ecdysis* sheds off the old exoskeleton. New exoskeleton develops from the underlying epidermis. 6. Presence of musculature with distinct striped muscles. 7. Body cavity or coelom is much reduced and acts as *haemocoel*. 8. Mouth and anus are present almost at the two terminal ends of the body. 9. Heart is placed on the dorsal side of the

alimentary canal. 10. Circulatory system is *open* type, i.e. blood vessels open within haemocoel. 11. Central nervous system includes a dorsally placed *brain* and solid, ventral double *nerve cord* with one fused *ganglion* in each segment. 12. Usually possesses *compound eye* (each eye is made up of several visual units). 13. Sexes are generally separate with the occurrence of sexual dimorphism. 14. Development may be *direct* or *indirect* (passes through larval stages which do not resemble the adult).

CLASSIFICATION IN OUTLINE

The members belonging to this large group exhibit certain close similarity. At the same time some of them resemble the annelids. Though several types of classificatory schemes are available, yet according to the most accepted view, the entire phylum is divided into four major groups—*Crustacea*, *Myriapoda*, *Insecta* and *Arachnida*.

The class *Trilobita* includes only extinct forms and exhibits primitive organisation. The group which includes the genus *Peripatus*, is called *Onycophora* and is considered as an appendix to the phylum. The detailed classification will be discussed after describing a few examples of the phylum.

Example of the Phylum Arthropoda—*PRAWN* (*PALAEMON*)

Several kinds of prawns and shrimps are available in our country. The example which is discussed here is commonly known as fresh-water prawn and its scientific name is *Palaemon carcinus*. It belongs to the class Crustacea. The other fresh-water prawns of our country are *Palaemon malcolmsonii* and *Palaemon lamarrei*.

Habit and Habitat

The prawn is common in rivers, ponds and other fresh-water areas. It is nocturnal, bottom-dweller and lives within underwater crevices and aquatic vegetations. It takes all kinds of food specially decaying leaves. It is a good swimmer but is also capable of crawling on the surface and at the time of danger can jump backwardly. It may attain a length up to seventy-five centimetres.

External structures

The body is elongated, hemispherical and slightly tapering at the posterior end (Fig. 16.2). The fresh specimen is slightly bluish in colour. The entire outer surface of the body is covered by hard exoskeleton. The body is distinctly divided into two parts—*cephalothorax* and *abdomen*. Both these parts bear on their ventral surfaces paired *appendages*, which are specialised for different functions. Each appendage is *biramous*, i.e. two branched, and in spite of their modifications are built up on the same general plan—(1) lower, double-jointed *protopodite* containing proximal *coxa* and distal *basis* and (2) two branches or *rami* on the basis, the outer one is *exopodite* and inner one is called *endopodite*. In addition to

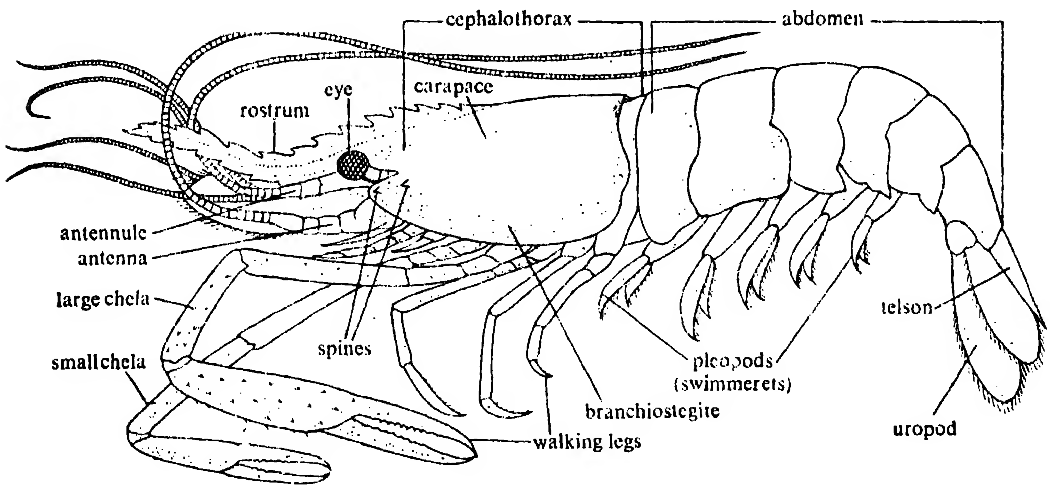


Fig. 16.2. Lateral view of a fresh-water Prawn (*Palaemon carcinus*).

the appendages, the two halves of the body bear several other structures.

CEPHALOTHORAX

Cephalothorax is the broad, unsegmented and cylindrical anterior part. It is formed by the fusion of *head* and *thorax*. In fact, during the development of prawn, one pre-segmental region and first fourteen segments fuse to form cephalothorax. The pre-segmental region remains in adult and carries the stalked eye and the first segment disappears during the process of transformation. A continuous shield-like exoskeletal covering, called *carapace*, encloses the cephalothorax. On both the ventro-lateral sides, the carapace hangs freely over the *gill-chamber* as *gill-cover* or *branchiostegite*. The branchiostegite is raised and lowered by a thin membrane, *branchiostegal membrane*. Ventrally, the carapace is covered by several hard *sternal plates*. Following structures are present on the cephalothoracic region: (1) ROSTRUM. On the dorsal and median surface, the carapace is drawn into a long serrated projection towards the anterior end. This is defensive in function. (2) EYE. Near the base of the rostrum and on each side of the carapace is placed an eye. Each eye is black and hemispherical and made up of several visual elements. It is thus called compound eye and it is mounted on a movable and jointed stalk. It is responsible for detecting light. (3) SPINES. These are small pointed structures, present in pairs on each lateral side of the carapace and posterior to each eye. The anterior pair is known as *antennal spines* and the short posterior pair is the *hepatic spines*. (4) APPENDAGES. Thirteen pairs of appendages are present on the ventral side of prawn. The close apposition of these appendages speaks about the fusion of cephalothoracic segments. The first five pairs, i.e. *First antenna* or *Antennule*, *Second antenna*, *Mandible*, *First maxilla* or *Maxillula* and *Second maxilla* are known as *cephalic appendages*. The remaining eight pairs are called *thoracic appendages* or *periopods*, which include three pairs of *Maxillipeds* and five pairs of *Walking legs*. (*a*) *First antenna* is also known as *antennule* (Fig. 16.3A). It is placed near the base of the eye stalk. Its protopodite carries an additional segment, a spiny *precoxa*. The basis is longer than coxa and probably its exo- and endopodites are modified as *feelers* or *flagella*. The outer feeler has two branches and the smaller branch carries *olfactory setae*, probably for determining smell. The

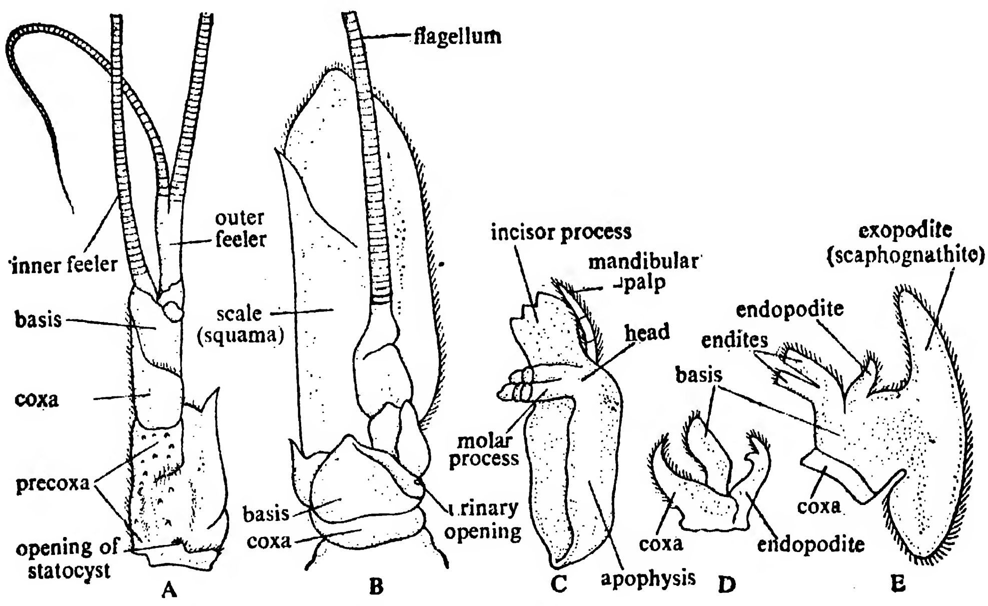


Fig. 16.3. Cephalic appendages of prawn (*Palaemon*). A. Antennule or First antenna. B. Second antenna. C. Mandible. D. First maxilla or Maxillula. E. Second maxilla.

precoxa carries the balancing organ, called *statocyst* and the coxa is beset with many sensory hairs. (*b*) *Second antenna.* It is situated immediately after the first antenna. The coxa contains a specialised organ called *green gland*, which serves as excretory organ. The exopodite is modified as a leaf-like *squama* or *scale* with setae along its inner margin (Fig. 16.3B). The scale serves as a balancer during swimming. The endopodite has become a long many-jointed flagellum and carries numerous *tactile setae.*

(*c*) *Mandible.* It is placed on the outer side of the mouth and is responsible for crushing the food. In its protopodite, the coxa is modified to form as spoon-shaped proximal *apophysis* and a solid distal part called *head* (Fig. 16.3C). The head contains stout *molar process* with five to six yellow teeth and thin *incisor process* with three closely set white teeth. The basis portion of protopodite and the endopodite form a three-jointed *mandibular palp,* which remains in front of the head of the mandible and carries sensory setae. The exopodite is absent.

(*d*) *First maxilla* or *Maxillula.* This crown-shaped smallest appendage (Fig. 16.3D) is placed slightly posterior to the mouth. It consists of three small leaf-like plates carrying sensory setae in their margins. Two of these plates (formed by coxa and basis) are projected inwards and are called *jaws* or *gnathobases* or *endites.* The remaining plate is endopodite and is directed outwards. The exopodite is absent. The first maxilla is responsible for pushing the food inside the mouth.

(*e*) *Second maxilla.* It is fan-shaped (Fig. 16.3E) and placed immediately after the first maxilla. The coxa is much reduced and the basis is bifurcated and directed inwards to form endites or jaws. The exopodite is large, fan-shaped and known as *scaphognathite* or *batar.* The endopodite is small and placed between the basis and exopodite. The second maxilla serves double functions—jaws are for food-getting and the scaphognathite is for producing constant water current within the gill-chambers.

(*f*) *First maxilliped.* The coxa and basis of the protopodite are flattened to become jaws and bear stiff setae on their inner margins (Fig. 16.4A). In addition to short endopodite and long exopodite, the coxa bears a bilobed *epipodite.* The exo- and endopodite parts of coxa together with basis help in the inpushing of food. The epipodites help in respiration.

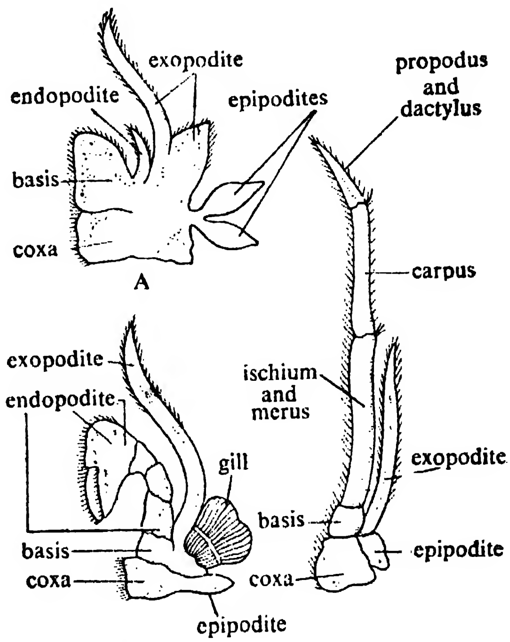


Fig. 16.4. Three maxillipeds of *Palaemon.* A. First maxilliped. B. Second maxilliped. C. Third maxilliped.

(*g*) *Second maxilliped.* Here the short coxa carries on its outer margin a small epipodite and a *gill* (Fig. 16.4B). The inner margin is lined with numerous setae. The exopodite is long and unjointed but the endopodite is made up of five segments—*ischium, merus, carpus, propodus* and *dactylus.* The last two segments are curved backwards to form a knife-like structure.

(*h*) *Third maxilliped.* This appendage is leg-like (Fig. 16.4C) and its coxa carries a thin epipodite on the outer side. The exopodite is thin and unjoined but the endopodite has three segments—proximal, middle and distal. The proximal segment is formed by the fusion of ischium and merus, middle is carpus and the distal segment is formed by the fusion of propodus with dactylus.

(*i*) *Walking legs.* There are five pairs of walking legs for crawling. Each leg has a short protopodite with distinct coxa and basis and a prominent five segmented endopodite (Fig. 16.5). These endopodite

segments are, *ischium*, *merus*, *carpus*, *propodus*, and *dactylus*. The epi- and exopodites are absent. The first and second legs possess *pincers* formed by the attachment of dactylus on propodus and are called *chelate* legs, while the rest are known as *non-chelate* legs. The second walking leg being the largest is known as *large chela* and the first walking leg is called *small chela*.

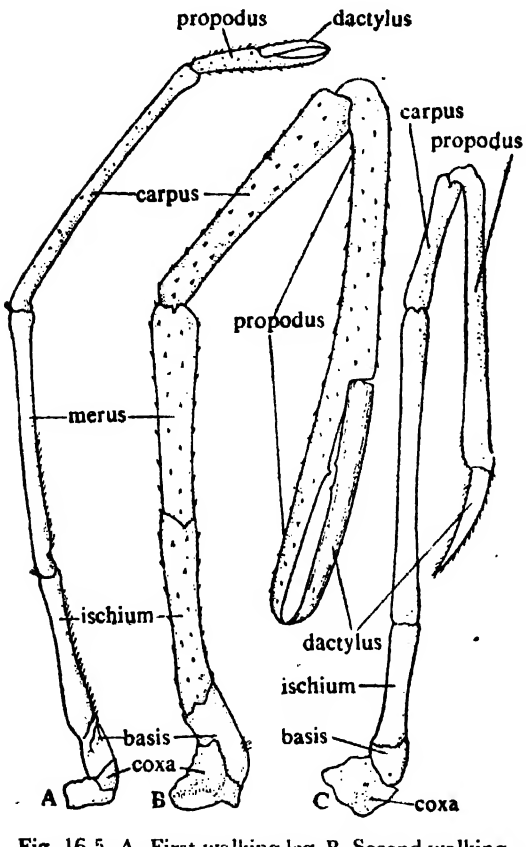


Fig. 16.5. A. First walking leg. B. Second walking leg. C. Third walking leg of *Palaemon*. Note that the prawn has five pairs of walking legs of which only the first and second pairs of legs are provided with spincers. The remaining three pairs are without spincers and resemble the third walking leg.

(5) Different apertures in cephalothorax. (*a*) *Mouth*. The mouth is a slit-like unpaired and median aperture on the ventral side of the cephalothorax and is situated in between third and fourth segments. It is encircled by mandibles, maxillae and first maxillipeds. It is concerned with the ingestion of food. (*b*) *Renal apertures*. It is present as a minute opening on a raised papilla near the base of each second antenna. It serves as an outlet of excretory duct from the excretory organ, green gland. (*c*) *Gonopores*. The position of these paired openings depends upon the sex of the individual. In males, the gonopores are seen on the inner sides of the coxae of fifth walking legs and in females these are in similar positions on the third walking legs. (*d*) *Statocyst openings*. The statocysts or the balancing organs of prawn communicate with the exterior through minute pores. There are two statocysts situated one on the base of each first antenna.

Abdomen

The abdomen is composed of six distinct segments and a posteriormost triangular *telson*. Each abdominal segment is laterally compressed and is bounded by a ring-like exoskeletal piece called the *sclerite*. The sclerite of one segment covers the sclerite of the following segment. Such imbricately arranged sclerites are united with each other by thin uncalcified *arthroidal membrane*. Each sclerite consists of a ventral plate-like *sternum* and a dorsal arch-shaped *tergum* (Fig. 16.6). The

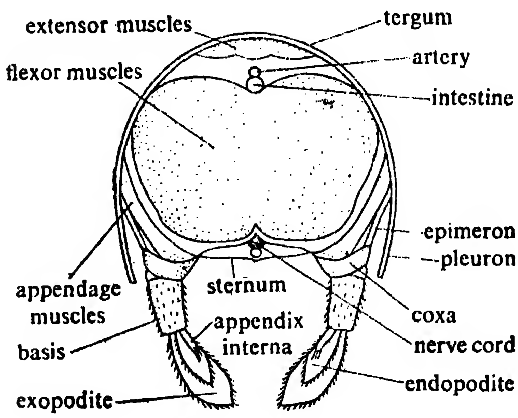


Fig. 16.6. Transverse section of a *palaemon* passing through the abdominal region.

tergum suspends freely on the lateral sides as *pleuron*. The pleuron is connected with the appendage of the corresponding side by a small plate-like *epimeron*. The imbricate arrangement of the sclerites and its hinge-like joints (marked by orange spots) permit free vertical movements of the abdomen. Each abdominal segment carries a pair of appendages on its ventral sides. These appendages are called *pleopods* and the last pair is modified and known as *uropods*.

(*a*) PLEOPODS OR SWIMMERETS. One pair of pleopods are present in each of the first five abdominal segments. In each pleopod the protopodite has a longer basis than the coxa (Fig. 16.7 A–C). The exopodite is longer than the endopodite. Both the exo- and endopodites bear tactile setae but the former is larger. An additional hook-like process, *appendix interna* is present on the inner sides of the endopodites of 2nd, 3rd, 4th and 5th pleopods. These processes of both the sides in females unite to form a basket for carrying eggs. The second pleopods of the male prawn have an additional process which is known as *appendix masculino*. The pleopods are primarily meant for swimming.

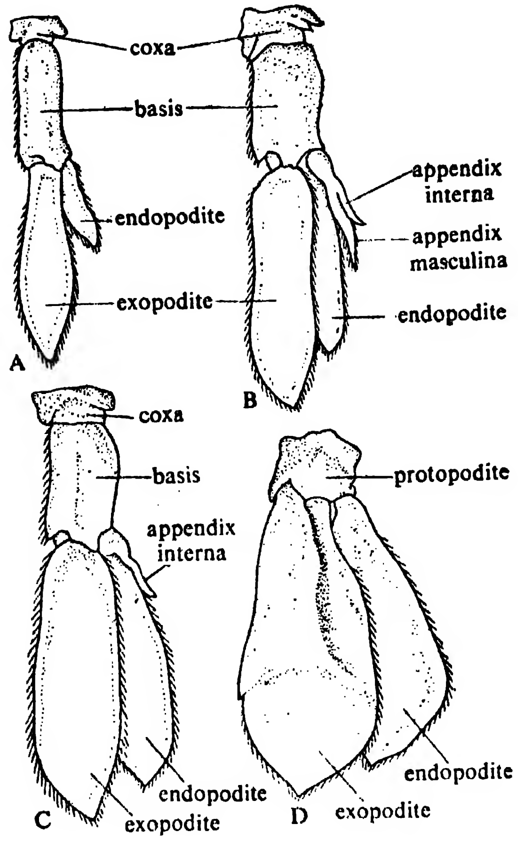


Fig. 16.7. A. First swimmeret, B. Second swimmeret, C. Third swimmeret and D. Uropod of *Palaemon*. Note that a male *Palaemon* can be distinguished from a female one by the presence of appendix interna.

(*b*) UROPOD. One pair of uropods is present in the last segment, one on each side of the telson (Fig. 16.7D). The protopodite is one segmented but the exo- and endopodites are large and fan-shaped. The exopodite is divided by a fine suture but the endopodite is not sutured. The tactile setae are arranged at the margin of both the exo- and endopodites. The uropods are used for changing direction and also for leaping backwards.

Only one aperture called *anus* is present near the base of the telson on its ventral side. This is the opening of alimentary canal for the purpose of egestion.

Locomotion

The prawn moves in three different ways—*crawling*, *swimming* and *darting*. At the time of crawling the animal straightens its body and rests over five pairs of walking legs. The legs are moved in harmony and the feelers of the antennae are directed forwards to survey the environment. The swimmerets move like paddle during swimming and look like oars.

The third type of locomotion, darting, occurs to evade danger. During this type of movement, the animal curves its abdomen under the cephalothorax and exerts pressure on the surface by the expanded uropods and telson. This gives a backward thrust, which shifts the body to a considerable distance in backward direction.

Digestive system

The digestive system consists of (A) *Alimentary canal* and (B) *Digestive glands* (Fig. 16.8).

A. **Alimentary canal.** The alimentary canal is distinctly divisible into three parts —*fore gut*, *mid gut* and *hind gut*.

1. FORE GUT. It is internally lined by thick cuticle and consists of following parts (*a*) *Mouth*. It is a broad opening on the ventral side of the cephalothorax between the third and fourth segments. It is bordered anteriorly by shield-like *labrum*, posteriorly by two-lobed *labium* and laterally by the incisor processes of the mandibles. (*b*) *Buccal cavity*. A small anterio-posteriorly *flattened* chamber between the mouth and oesophagus. It has an irregularly folded lining of cuticle. (*c*) *Oesophagus*. It runs vertically upwards as a broad tube from the buccal cavity and leads to the stomach. The inner lining is muscular and has one anterior, two lateral and one posterior folds. (*d*) *Stomach*. This is the longest part of the fore gut which is placed longitudinally

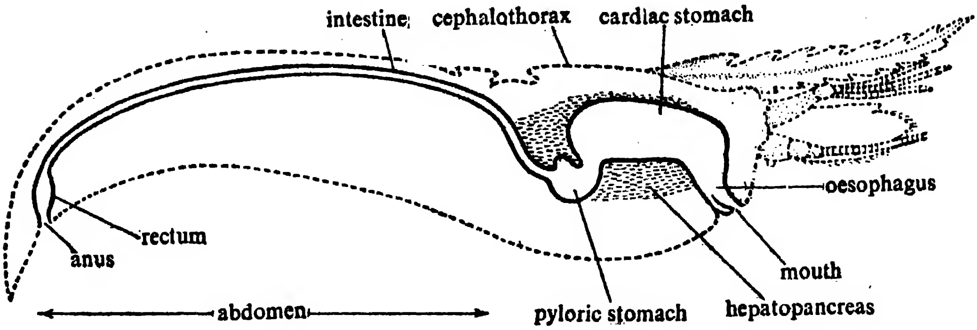


Fig. 16.8. Lateral view of alimentary system in *Palaemon*. The outline of the body is drawn to indicate the position of the different parts of alimentary canal.

within the cephalothorax. It is divided into two parts: (*i*) *Cardiac stomach*. It is large, spacious and bag-like anterior part of the stomach. Its inner cuticular wall is provided with ridges having minute bristles. Following plates support its wall—*circular plate* in the anterior part, *lanceolate plate* on the dorsal side of the posterior part and a shield-shaped *hastate plate* in the mid-ventral region. (Fig. 16.9). The posterior part

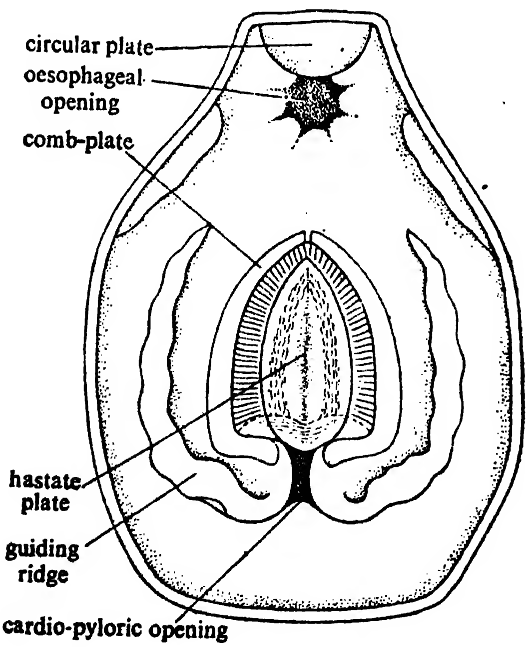


Fig. 16.9. Floor of the cardiac stomach of *Palaemon* as seen in longitudinal section.

of the hastate plate is depressed and reaches up to the cardio-pyloric opening. The upper part is slightly convex and gradually slopes towards the two lateral sides from a distinct *median ridge* in the middle. Both the upper and posterior surfaces have delicate setae. On each lateral side of the hastate plate lies an elongated *lateral groove*. A cuticular *supporting rod* and a *ridged plate* of similar nature, bound the inner and outer sides respectively of each lateral groove. The inner side of each ridged plate is provided with rows of comb-like setae, which are known as *comb-plate*. The bristles of the comb-plate partially cover the lateral side of the hastate plate. The comb-plates of two sides unite at the anterior end but remain free at the posterior end just near the cardio-pyloric opening. The inner wall of the cardiac stomach on the side of each comb-plate is folded to form a longitudinal channel, called the *guiding ridge*. The two guiding ridges posteriorly form the border of the cardio-pyloric opening. (*ii*) *Pyloric stomach*. The cardiac stomach opens within the next part, pyloric stomach through a narrow, X-shaped cardio-pyloric opening. The opening is guarded by one anterior, one posterior and two lateral valves. The anterior valve is the posterior extension of hastate plate, posterior one is the fold of stomach wall and the two lateral valves are the projections of the guiding ridges. The pyloric stomach is much smaller and narrower than cardiac stomach. Its lateral muscular wall is incompletely divided by folds into a small *dorsal chamber* and large *ventral chamber*. The ventral chamber receives the duct from the digestive gland, hepatopancreas and is divided into two lateral compartments. The floor of the ventral chamber has a rectangular *filter plate* having alternate ridges and grooves. This filter plate together with the bristles on the lateral wall of ventral chamber, acts as *pyloric filtering apparatus*. This filter

permits only liquid food to enter into the intestine.

2. Mid gut. It is the narrow and elongated part of the intestine, which begins from the dorsal chamber of pyloric stomach and runs along the mid-dorsal line up to the sixth abdominal segment. Its internal epithelial lining at the posterior part is folded. Thus the space within the tube is reduced.

3. Hind gut. It is also lined by thick cuticle and consists of following parts: (*a*) *Rectum*. It is the swollen muscular region of the last part of intestine having numerous internal folds. (*b*) *Anus*. This is the aperture through which the alimentary canal opens to the exterior. It is a ventrally placed longitudinal slit-like opening, present near the base of the telson on a raised papilla.

B. **Digestive gland.** Only one digestive gland, *hepatopancreas*, is present. It is an orange-yellow coloured, loosely arranged bilobed organ which encircles completely the pyloric stomach, part of the intestine and partly the cardiac stomach. One hepatopancreatic duct originates from each lobe independently and opens separately within the pyloric stomach, immediately after the pyloric filter plate. The hepatopancreas in its role as digestive gland serves as liver, pancreas and intestine of higher animals. In addition, it absorbs digested food and can store it for future use. Thus, this organ serves double functions—digestion and storage.

Mechanism of Nutrition

The process of nutrition involves three stages—*ingestion*, *digestion* and *egestion*.

Ingestion. Prawn is omnivorous, i.e. eats all kinds of foods. It feeds actively at dusk and in the morning on algae, decaying vegetables and small insects. Food is procured by the chelate legs and brought near the mouth cavity by following appendages—maxillipeds, maxillulae and maxillae. Mandibles help to fragment the food into smaller bits and the molar processes of the mandibles inside the buccal cavity crush the food. Entrance of food within the cardiac stomach is assisted by the peristaltic motion of the oesophageal wall.

Digestion. Within the cardiac stomach the food is churned by the action of cuticular plates on the inner wall. Finer particles of food being filtered by the comb-plate come within lateral grooves from where it is guided into the ventral chamber of pyloric stomach. Digestion takes place within the pyloric stomach by the action of digestive juices which come from the hepatopancreas. All the enzymes for the breakdown of carbohydrate, protein and lipid are present in the juice. The digested liquid food is strained by the filtering apparatus in the ventral chamber of pyloric stomach and enters within dorsal chamber and then to the hepatopancreas. The residual part of the food passes within the mid gut. After certain amount of absorption the residual matter enters within dorsal chamber and then to the hepatopancreas. The residual part of the food passes within the hind gut.

Egestion. From intestine the residual part of the food enters within the rectum and is temporarily stored there for sometime. Finally it is ejected through the anus.

Respiratory system

Prawn respires in the aquatic medium and it carries three sets of organs for the purpose—*lining of the branchiostegite*, *epipodites* and *gills*. All these organs are enclosed within a special chamber on each side of the cephalothorax, which is called *gill-chamber*. The gill-chamber is covered by the lateral extension of carapace called *gill-cover* or *branchiostegite*. Each gill-chamber is thus open ventrally, anteriorly and posteriorly.

A. **Lining of the branchiostegite.** The richly vascularised membrane of the branchiostegite serves as respiratory surface, through which gaseous exchange takes place.

B. **Epipodites.** These are small highly vascularised leaf-like membranous structures, one on the coxal segment of each maxilliped. These epipodites being present in the anterior part of the gill-chamber carry out respiratory functions.

C. **Gills.** Among the three sets of respiratory organs, the gills are regarded as primary respiratory organs. On each lateral side of the cephalothorax and beneath the branchiostegites, there are eight gills (Fig. 16.10), each attached with the thoracic wall by a *gill-root*. Seven of these eight gills are serially arranged, while the eighth gill remains concealed under the second gill.

The gills are crescent-shaped and their sizes increase gradually from anterior to posterior direction. Each gill consists of a slender *axis* or *base* on which double rows of rhomboidal leaf-like gill-plates are arranged like the pages of a book.

Two *lateral* and one *median longitudinal blood channels* pass throughout the length of gill base. The two lateral channels are interconnected by numerous *transverse channels*. From each lateral channel a slender *marginal channel* is given to each plate.

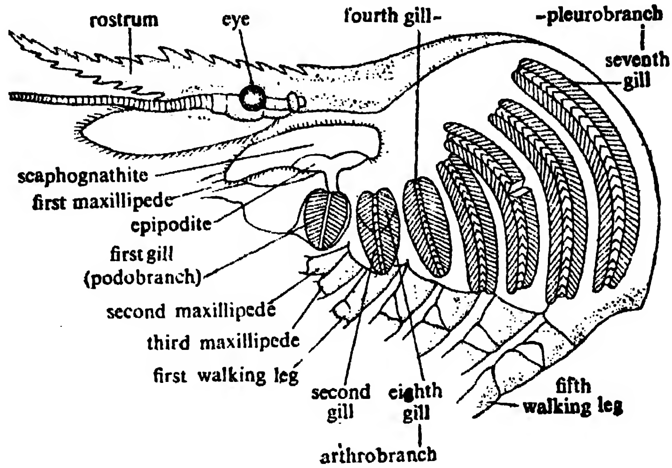


Fig. 16.10. Respiratory organs (Gills) of *Palaemon*. Note that the branchiostegite of one side has been removed to expose the gill-chamber.

According to their position and mode of attachment, the gills are of three types: (*i*) *Podobranch*—attached with the coxa of the second maxilliped. (*ii*) *Arthrobranch*—attached with the arthroidal membrane of third maxilliped. (*iii*) *Pleurobranch*—attached with the outer border of the thorax and over the articulating surface of the walking legs. In prawn, the first gill is podobranch, second and eighth gills are arthrobranchs and remaining five gills are pleurobranchs.

Histological structure of the gill shows that gill base has following layers—the outermost *cuticle*, inner *epidermis* and innermost *connective tissue mass*. Each gill-plate is formed by monolayer of cells, sandwitched between two layers of cuticle. The cellular layer includes two alternately arranged cell types—*pigmented* and *transparent*.

After covering the entire margin of the plate, the marginal channel opens within the *median channel*. The gill receives deoxygenated blood through *afferent branchial channels*. Each branch of afferent channels opens within the transverse channels. From transverse channels the blood passes to the lateral longitudinal channels and is distributed subsequently within the gill-plates through the marginal channels. After oxidation, the blood from marginal channel returns to the median channel and then to the efferent branchial vessels, which convey it to the heart. The course of circulation of blood through the gill is given below:

Afferent branchial channels → Transverse channels → Lateral longitudinal channels
↓
Marginal channels
↓
Heart ← Efferent branchial channels ← Median longitudinal channels

Mechanism of Respiration

The scaphognathites of maxillae and exopodites of maxillipeds are responsible for forcing the water to rush inside the gill

chamber through posterior and lateral sides. This water passes out through the anterior end. During the flow of water the vascularised surface of the branchiostegites, gills and epipodites are bathed and gaseous exchange occurs through these areas when dissolved oxygen is taken in and carbon dioxide passes from the body to the exterior.

Circulatory system

The blood circulation in prawn is open type, i.e. blood flows through the body spaces. Such spaces are called *haemocoels*. The circulatory system includes —*blood*, *heart*, *true blood vessels* and *haemocoelomic spaces*.

A. **Blood.** Blood includes both the circulating fluid and the body fluid. The cellular part of the blood includes only amoeboid *leucocytes*. The liquid part, *plasma* contains a copper-containing respiratory pigment *haemocyanin* in dissolved state. This pigment is responsible for the blue colouration of the blood. The blood can coagulate very rapidly.

B. **Heart.** It is more or less a triangular organ with inner spongy cavity. It is placed beneath the carapace and above the gonads. Heart is united with the pyloric stomach by a *cardio-pyloric strand*. The anterior end of the heart, called the *apex* is pointed and the broad end *base* is directed posteriorly. The entire structure is enclosed within a haemocoelomic space called *pericardial sinus* the wall of which serves as *pericardium*. Two *lateral* and one *median* *longitudinally fibrous tissue strands* connect the heart with the body wall and thus fix it to its position inside the pericardium. The wall of the heart is pierced by five pairs of slit-like openings called *ostia*. There are two pairs on the lateral sides, one pair in the ventral, one pair in dorsal and a pair at the posterior end of the heart. These ostia are contractile and work as valves to permit only flow of blood from pericardial sinus to the heart.

C. **True blood vessels.** These are the vessels which possess definite walls. As all of them originate from the heart to supply blood to different parts of the body, they are better called *arteries*. From the heart of prawn six large vessels originate. They are : (*i*) single *ophthalmic* artery, (*ii*) paired *antennary* arteries and (*iii*) paired *hepato-pancreatic* arteries all originate from the anterior end and (*iv*) a single *mid-posterior* artery emerges from the posterior end (Fig. 16.11).

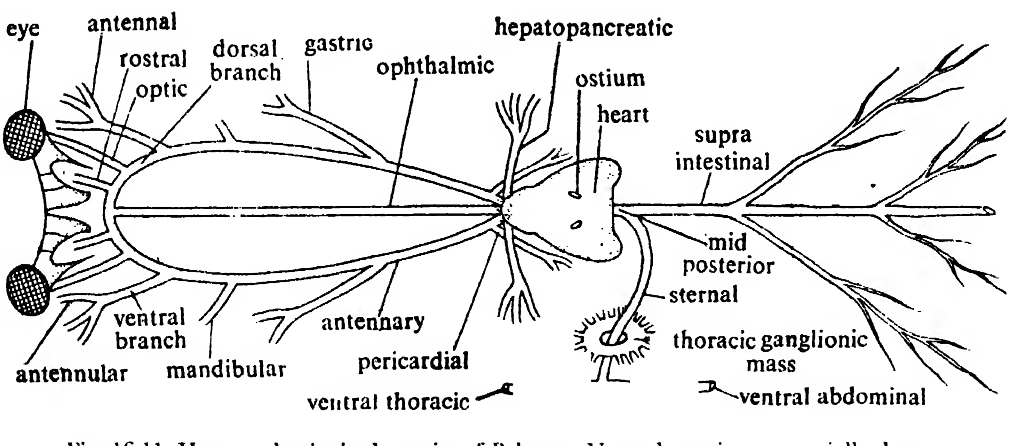


Fig. 16.11. Heart and principal arteries of *Palaemon*. Ventral arteries are partially drawn.

(*i*) Ophthalmic artery. The single ophthalmic or cephalic artery originates from the apex of the heart and runs anteriorly along the mid-dorsal line up to the base of the rostrum and unites with the branches of two antennary arteries.

(*ii*) Atennary artery. Each antennary artery originates from the heart and from the sides of the ophthalmic artery. It runs anteriorly along the outer border of the mandibular muscle. Each antennary artery sends the following branches on its own side—(*a*) *Pericardial branch* to supply blood to the pericardial wall, (*b*) *Gastric branch* to supply blood to the cardiac

stomach and (*c*) *Mandibular artery* to the muscle of the mandible. Each antennary artery then splits into (*d*) a *ventral* and (*e*) a *dorsal* branch. The ventral branch supplies vessels to the first and second antennae. The dorsal branch sends an optic artery to the eye and then the two dorsal branches of the two antennaries unite with the median ophthalmic artery to run within the rostrum as a paired *rostral arteries*.

(*iii*) HEPATOPANCREATIC ARTERY. The hepatopancreatic or hepatic artery of each side originates from the posterio-median end of the heart and runs transversely to enter within the hepatopancreas.

(*iv*) MID-POSTERIOR ARTERY. The mid-posterior artery immediately after originating from the posterio-median end of the heart divides into (*a*) supra-intestinal artery and (*b*) sternal artery. The supra-intestinal which is also known as dorsal abdominal artery runs posteriorly along the mid-dorsal line up to the hind gut. It supplies the alimentary canal and the muscles on the dorsal sides. The sternal artery runs transversely towards the ventral side. It pierces the thoracic ganglion mass and bifurcates into an anteriorly directed

D. **Haemocoelomic spaces.** Small haemocoelomic spaces are called lacunae. These lacunae open into larger spaces called sinuses. The passages connecting lacunae and sinus or two sinuses are known as haemocoelomic channels. Blood after flowing through different small haemocoelomic spaces or lacunae is collected in a pair of common elongated space called *ventral sinus*. These are placed beneath the hepatopancreas and continued up to certain length within the abdomen. The two ventral sinuses are interconnected by several small slender channels.

From the ventral sinus six *afferent branchial channels* take the deoxygenated blood to the gills. First afferent branchial channel supplies blood to the podobranch and arthrobranchs while the remaining five vessels supply to the five pleurobranchs.

From gills oxygenated blood is collected by six pairs of *efferent branchial channels* and is finally drained into *dorsal* or *pericardial sinus*.

MECHANISM OF BLOOD FLOW. The heart contracts to drive the oxygenated blood to the different parts of the body through arteries (Fig. 16.12). These arteries instead

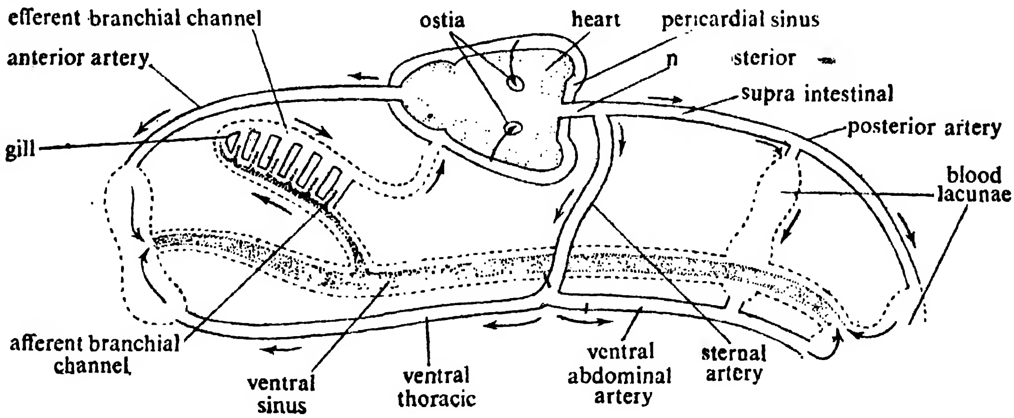


Fig. 16.12. Schematic route of blood flow in *Palaemon*.

ventral thoracic and a posteriorly directed *ventral abdominal* arteries. The ventral thoracic artery supplies blood to the different parts on the ventral side of the cephalothorax and ventral abdominal sends branches to the ventral side of the abdomen.

All the arteries ultimately break up into finer branches and open within the haemocoelomic spaces. Thus the circulatory system of prawn lacks network of capillaries.

of forming capillary network open directly within haemocoelomic spaces. From different haemocoelomic lacunae deoxygenated blood is collected within paired ventral sinuses. From these large spaces, blood is sent for oxidation to the respiratory organs through the afferent branchial channels. From gills the blood returns to the pericardial sinus through efferent branchial channels. When the pericardial sinus is full its wall starts to contract

and forces the blood to enter within the heart through ostia. When heart contracts the lip-like borders of the ostia close and thus blood is permitted to travel only through arteries.

Excretory system

Excretory organs are known as *green glands* or *antennary glands* (Fig. 16.13).

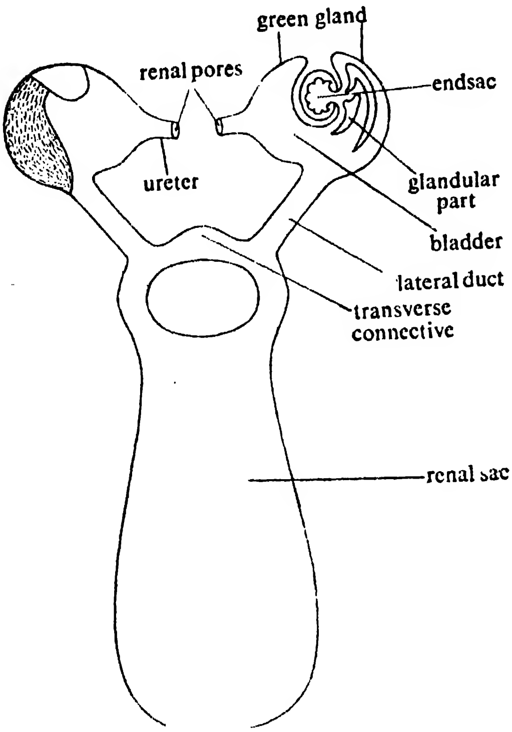


Fig. 16.13. Diagrammatic view of the excretory organs of *Palaemon*. These are called green glands or antennary glands and here the gland of the right side has been dissected to show the internal structures.

These are paired white organs. Each organ remains within the coxa of each second antenna. The organ consists of following parts: (A) **End sac.** This small bean-shaped part contains a blood lacuna. Its wall is two-layered, the inner layer is of epithelial cells having excretory function and the outer thick connective tissue layer has minute lacunae. Radially arranged partitions called *septa*, project from the wall within the central cavity. (B) **Labyrinth.** Present outside the end sac and contains many narrow, branched and coiled excretory tubules. Each tubule communicates with the end sac by a single opening but opens within the bladder through several apertures. A single epithelial cell layer having excretory function lines each tubule. (C) **Bladder.** It is a thin-walled sac with an epithelial lining. It communicates with the exterior through a small ureter. (D) **Excretory opening.** It is present on the base of each second antenna.

Both the green glands are connected with a common large thin-walled transparent and centrally placed sac called the *renal sac*. It is present between the cardiac stomach and the carapace and it communicates with the bladder of each green gland by a separate *lateral duct*. The two lateral ducts are interconnected by a *transverse connective.*

End sac and the labyrinth are the two regions responsible for extracting urine from the blood. The excretory product includes ammonia (excreted by end sac), uric acid, other nitrogenous compounds and excess water (excreted by other parts). The urine remains temporarily stored within the bladder and is periodically expelled through renal pores.

In addition to green glands, gills and integumental covering are also responsible for excretion. The exoskeleton at the time of its periodic replacement carries a large quantity of excretory products.

Nervous system

Nervous system resembles the annelidan pattern but shows considerable advancement. It is divisible into (A) *Central nervous system*, (B) *Peripheral nervous system* and (C) *Autonomic nervous system*. It also includes several *sense organs* to permit the entry of different messages from outside.

A. **Central nervous system.** The central nervous system runs from anterior to posterior end (Fig. 16.14) and contains following structures: (1) BRAIN. It is made up of a pair of *supraoesophageal ganglia* which are placed dorsally and near the base of the rostrum. It sends a number of peripheral nerves to the different organs at the anterior end of the cephalothorax. (2) CIRCUM-OESOPHAGEAL CONNECTIVES. These are paired cords, each of which begins from the supra-oesophageal ganglion of one side and runs posteriorly along the ventro-lateral wall of the cephalothoracic cavity. A small ganglion is present in each commissure to supply nerve to the

mandibles. The two cords are connected by a thin nerve called *transverse loop*, which is present immediately after the oesophagus. The two connectives ultimately unite at the floor of the thoracic cavity with a large ganglion, called the *thoracic ganglionic mass*. (3) THORACIC GANGLIONIC MASS. A large ventral elongated mass is formed by the fusion of eleven pairs of ganglia. Two circum-oesophageal connectives are united with it at the anterior end. This ganglionic mass is pierced by the sternal artery. It sends eleven pairs of peripheral nerves. (4) VENTRAL NERVE CORD. From the posterior end of the thoracic ganglionic mass originates ventral nerve cord which runs up to the posteriormost segment. The cord appears to be single but in reality it is formed by the fusion of two separate cords. The ventral nerve cord along its course bears a ganglion in each segment. The last ganglion or 6th ganglion is the largest of all the abdominal ganglia and known as *stellate ganglion*.

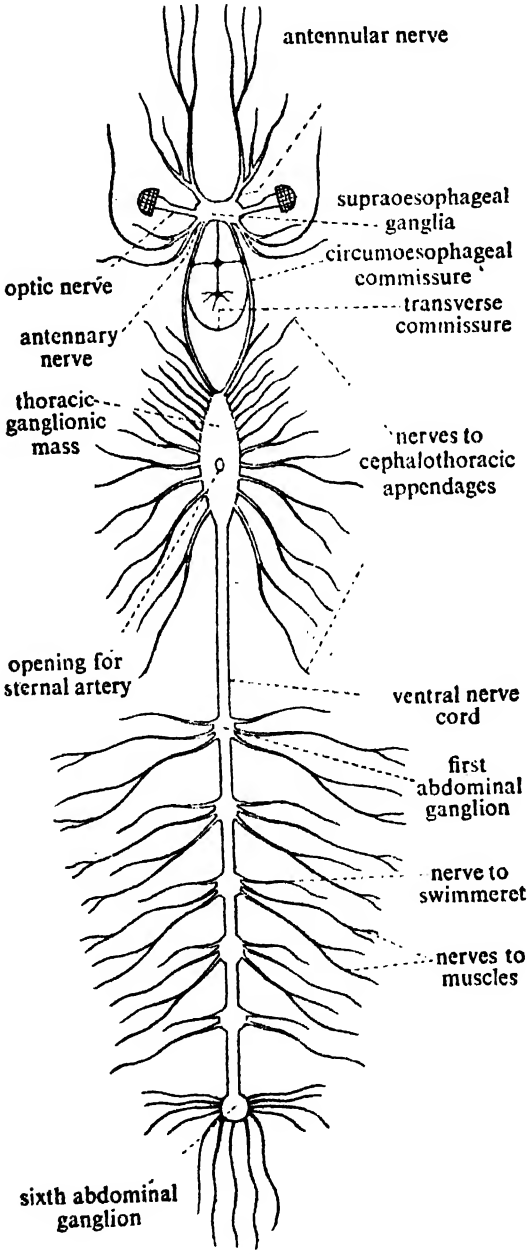


Fig. 16.14. Nervous system of *Palaemon* (after Patwardhan).

B. **Peripheral nervous system.** The peripheral nerves are given off from the different parts of the central nervous system. Each peripheral nerve contains two kinds of fibres—*sensory* and *motor*. The sensory fibres carry instructions from the central nervous system to different parts and the motor fibres are meant for bringing messages from different corners of the body. Following peripheral nerves are seen in prawn: (1) OPTIC NERVE. From each lobe of brain, an optic nerve enters within the eye to innervate the retinal layer. (2) ANTENNULAR NERVE. From each lobe of brain an antennular nerve is given within the first antenna or antennule to supply statocyst and various other structures present in the first antenna. (3) ANTENNARY NERVE. From the posterior side of each lobe of brain, antennary nerve originates and runs posteriorly to take a quick turn towards the anterior direction to supply the various parts within second antenna including green gland. (4) CEPHALOTHORACIC NERVES. Eleven pairs of cephalothoracic nerves originate from the thoracic ganglionic mass to supply different muscles and appendages in that region. (5) ABDOMINAL NERVES. From each abdominal ganglion two pairs of peripheral nerves are given off to the corresponding segments to supply muscles and appendages. The stellate ganglion in addition to these two pairs sends several more branches to telson, rectum and other adjoining structures.

C. **Autonomic nervous system.** It includes a few minute ganglia and slender nerves which are present over the cardiac stomach to supply involuntary parts of the body.

D. **Sense organs.** Following sense organs are present in prawn to receive different

stimuli—tactile organs, olfactory setae, statocyst and eye.

1. TACTILE ORGANS. These sense organs are present along the margin of antenna and other appendages. A typical tactile seta (Fig. 16.15A) consists of (*a*) swollen *base* or *shaft* and (*b*) pointed *plumose* with double rows of barbs. These are responsible for the sensation of touch.

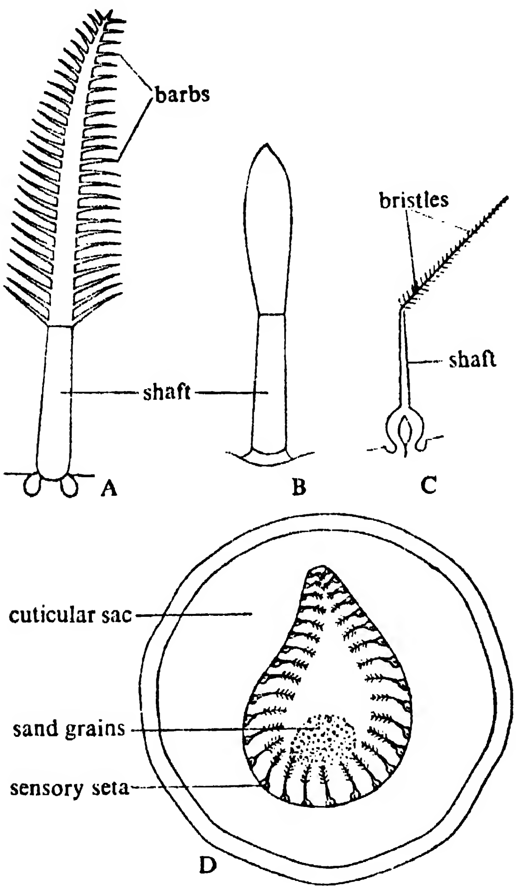


Fig. 16.15. A–C. Different sensory setae of *Palaemon*. A. Tactile seta. B. Olfactory seta. C. Statocystic seta. D. Statocyst of *Palaemon* (sectional view)—note the arrangement of sensory setae (after Patwardhan).

2. OLFACTORY SETAE. These organs are present on the small inner branch of the outer feeler of the first antenna. These organs differ from tactile setae in the absence of the barbs in the plumose part (Fig. 16.15B). These are responsible for smell.

3. STATOCYST. Inside the base (precoxa) of each antennule, the statocyst is present as a small, white and spherical cuticular sac. In the central part of the sac, elongated and slender sensory setae are elliptically arranged. Each seta (Fig. 16.15C) consists of a pointed bristled end called *shaft*, which is directed inwards and an outer swollen *base* which is connected with a fine branch of statocyst nerve. In the area surrounded by the setae there are minute sand grains (Fig. 16.15D). When the prawn moves, these inner sand grains are displaced at each change of position. These displaced sand particles press against the sensory setae. Finer branches of statocyst nerve carry the information from each seta to the brain and the animal corrects its loss of equilibrium.

4. EYE. Each movable and stalked eye is compound in nature, i.e. made up of several simple visual units (Fig. 16.16A). Each unit is called an *ommatidium* or *ocellus*.

(*a*) *Structure of an ommatidium*

Each ommatidium is divisible into two parts—outer *dioptrical region* for focussing and inner *retinal part* for receiving light stimuli. These two portions in each ommatidium contain following parts from outer to inner sides: (*i*) *Cornea*. It is the outermost transparent cuticular layer. The cornea of all the ommatidia gives the outermost part of the eye a graph paper-like appearance (Fig. 16.16B) and each square is called a *facet*. (*ii*) *Corneagen cells*. Immediately beneath the cornea a pair of corneagen cells is present which are responsible for the replacement of cornea (Fig. 16.16C). (*iii*) *Crystalline cone*. This is an elongated transparent body, placed beneath the corneagen cells and works as lens. (*iv*) *Cone cells* or *Vitrellae*. These cells are four in number and they encircle the cone or lens to provide nourishment. (*v*) *Rhabdome*. Elongated transversely striated body which is situated immediately beneath the cone cells. (*vi*) *Retinular cells*. These are elongated sickle-shaped cells. Seven such cells secrete the rhabdome and encircle it to provide its nutrition. (*vii*) *Pigment sheath*. Two separate sheaths containing chromatophores are responsible for separating one ommatidium from the other. The group of pigment sheath which is present around cone and cone cells is called *iris sheath*. While the other group around rhabdome and retinular cells is called *retinal sheath*. Pigment sheaths are able to

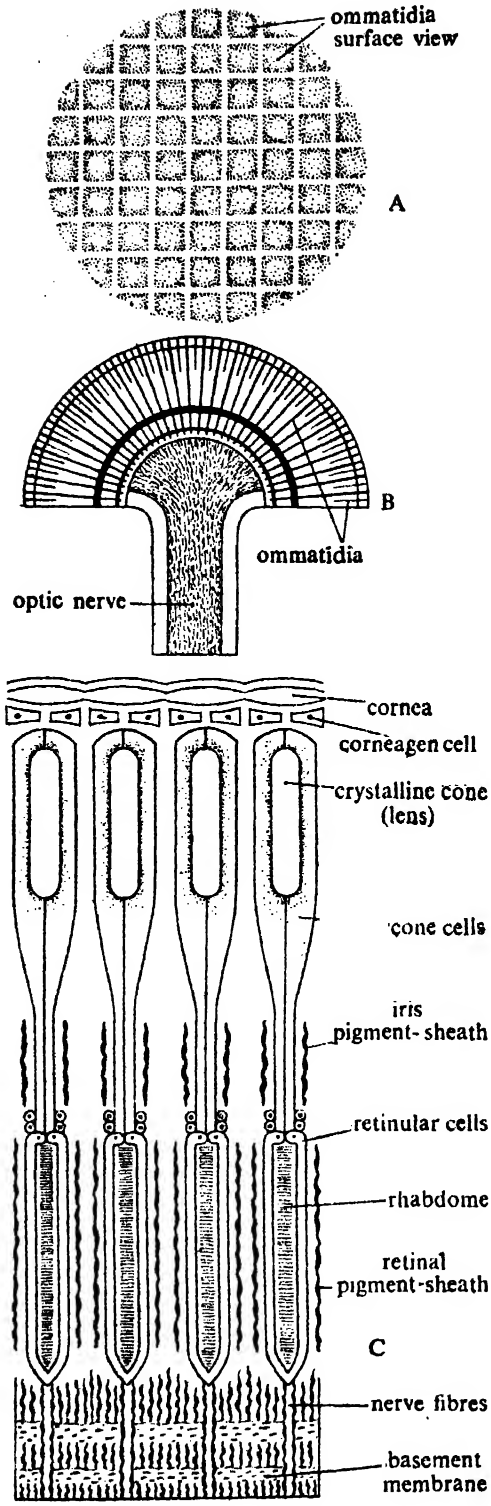


Fig. 16.16. A. Compound eye of *Palaemon* (surface view). B. Compound eye of *Palaemon* (longitudinal section, diagrammatic). C. Histological structure of four ommatidia (longitudinal section, diagrammatic).

contract and relax, which depends upon the intensity of light.

(*b*) *Mechanism of image formation*

The ommatidia may work singly or collectively. During bright light both the pigment sheaths extend and completely separate the ommatidia, which results in the formation of a large number of images. These images are called ***apposition images***. This type of vision is called ***mosaic vision***. When light is dim, pigment sheath contracts and all the ommatidia work together to form a single but blurred image. Such image is called ***superposition image*** and the kind of vision is known as ***superposition image***. Prawn can move its eye considerably and has nearly 360° vision.

Reproductive system

Sexes are separate in prawn and sexual differences (i.e. sexual dimorphism) are prominent. The gonads are of different shapes and both occupy similar position. The important differences between two sexes are shown in the table -1 Arthropoda.

Male reproductive system. It consists of following structures (Fig. 16.17A): (1) *Testes*. These paired, soft and white organs are present above the hepatopancreas and beneath the heart. Anterior ends of the two testes are united but the posterior ends are free. Each testis includes numerous minute tubes called *seminiferous tubules* which remain enclosed within connective tissue. Each tubule has an inner lining of a single layer of epithelial cell which transforms into spermatozoa. (2) *Vas deferens*. From the posterior end of each testis, a long much-coiled duct, called vas deferens originates. It runs obliquely downwards and backwards between the thoracic wall and abdominal flexor muscles towards the fifth walking leg. (3) *Seminal vesicle*. Each vas deferens near the base of the fifth walking leg is swollen as seminal vesicle. It serves as a chamber in which sperm cells are temporarily stored and transformed into small packets called *spermatophores*. (4) *Male gonopore*. The base of each fifth walking leg contains a small opening called male gonopore, through which the seminal vesicle of the corresponding side opens. The gonopore is guarded by a small cuticular lid.

Female reproductive system. It consists of following structures (Fig. 16.17B): (1) *Ovaries*. These paired white and

TABLE 1—ARTHROPODA

Differences beteen a Male and a Female Prawn

Male	Female
1. Among the specimens of same age, the size is large.	1. Size comparatively smaller.
2. Abdomen is narrow.	2. Abdomen is proportionately broad.
3. Walking legs are closely set.	3. Walking legs are set apart.
4. Second walking leg is strongly developed and with numerous spines.	4. Second walking leg is moderately developed.
5. *Appendix masculina* is present in the second pleopod.	5. Absent.
6. Testes are elongated with a long median gap for cardio-pyloric strand. Posterior ends are free.	6. Two ovaries are fused at both the ends and the median gap is short.
7. First part of the reproductive duct, *vas deferens*, is coiled.	7. The oviducts are straight.
8. Reproductive openings or *gonopores* are present near the base of *fifth* walking legs.	8. Gonopores are present near the base of *third* walking legs.

compact organs are placed above the hepatopancreas and beneath the heart. The two ovaries are united at their both ends. Each ovary is bounded by a hard capsule within which egg cells or ova remain serially arranged. The matured eggs remain near the margin and the immature eggs occupy the centre.

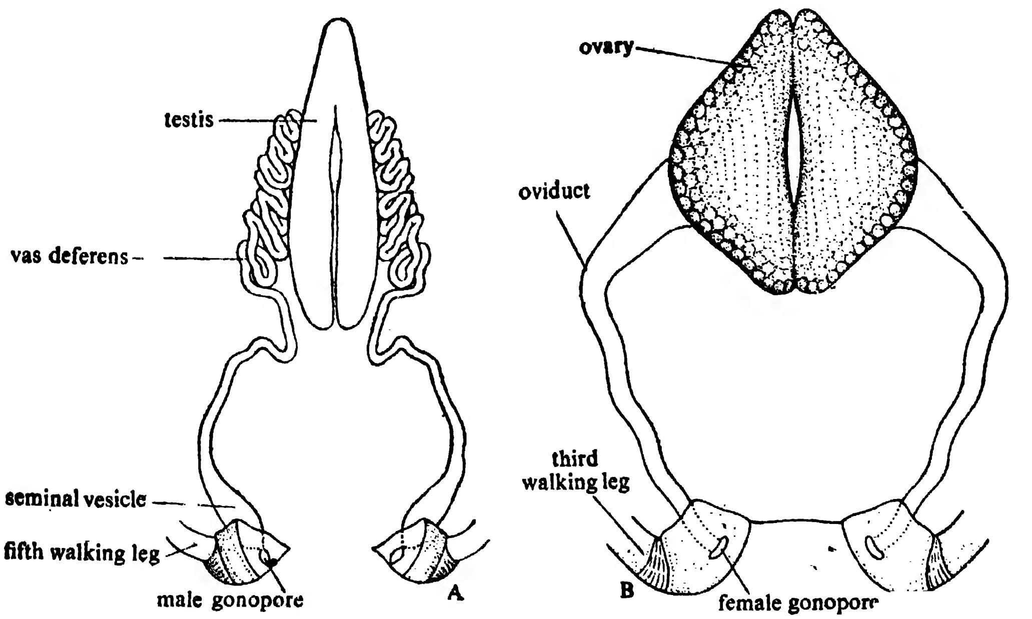


Fig. 16.17. A. Male reproductive system of *Palaemon*. B. Female reproductive system of *Palaemon* (after Patwardhan).

(2) *Oviducts.* From the outer border and from near the middle of each ovary originates a short and wide oviduct which runs straight downwards to the third walking leg. (3) *Female gonopore.* Present one on the inner side of each third walking leg as a small aperture is called the female gonopore or reproductive opening. It acts as an outlet of oviducts.

Breeding and Life history

Sperm cells are umbrella-like. The eggs or ova are round, yolk-filled and each egg contains a large nucleus. Reproduction takes place during rainy season. Fertilization is external, i.e. union of reproductive cells occurs outside the body. The female prawn carries the fertilized eggs within the abdominal basket. The development is direct, i.e. young which hatches out of the egg resembles the adult in appearance. Quick moulting occurs during the growth of the young.

EXAMPLE OF THE PHYLUM ARTHROPODA—*TRUE CRABS*

Like prawn, the crabs are included within the class *Crustacea*, but its organisation is more complicated due to more closer approximation of the segments. The well-known crabs of our country include genera like *Carcinus*, *Portunus* and *Cancer*.

Habit and Habitat

The crabs are of several types and vary in size, shape and colouration. The crabs may be marine and fresh-water. Though its body is adapted for aquatic respiration, it may live for a considerable period on land. The crabs dig burrows on the shores or banks of rivers and ponds. These animals come out for feeding, but with the slightest disturbance swiftly return to the hole. On land the crabs do lateral movement with the help of walking legs. Some crabs which live mostly in water have appendages more adapted for swimming.

External structures

The body is more or less oval in outline and the breadth is greater than the length (Fig. 16.18). The body of crab is divisible into *cephalothorax* and *abdomen.*

CEPHALOTHORAX

This is the most prominent part in the crab and is covered dorsally by a flat broad and oval *carapace* which is made up of fused *tergites.* The anterior and lateral margins of the carapace are semicircular and spiny. The ventral side of the cephalothorax is covered by *sternites* and its lines of fusions are well-marked. The sternites extend inside the body as folds. Such folds are known as *apodemes.* These apodemes being united with each other form a continuous ventral framework called *endophragmal skeleton.* This supporting framework provides the region for the attachment of muscles. The carapace is strongly calcified but the sternites are uncalcified. The exoskeleton which covers the two sides of the cephalothorax are known as *pleuron.* The margin of the carapace which extends laterally is called the *pleural fold.* On each side the pleural fold is separated into an anterior *pterygostomial region* and a posterior *branchiostegite.* The pterygostomial region is immovable and separated from the carapace by a *pleural suture.* The branchiostegite is continuous with the carapace and forms the outer covering of the gill chamber. The rostrum is absent in crab. Following structures are seen in the cephalothoracic region. (*a*) MOUTH. It is a square opening on the ventral side of the anterior end. (*b*) EYE. At the anterior margin of the carapace one pair of stalked compound eyes is placed within definite sockets. The stalk is two-jointed and movable. (*c*) APPENDAGES. The appendages are jointed and are of same numbers as seen in prawn, but are structurally different. The cephalic appendages (Fig. 16.19) include (*i*) *Antennule* or *First antenna.* These are small paired retractile appendages which usually remain folded sidewise and placed within sockets. (*ii*) *Second antenna.* Usually these paired appendages are small and erect. In one genus of crab (*Corystes* sp.), the two second antennae anastomose to form a tube through which water is sucked in for respiration. This tube filters the sand particles from water. When the animal remains within the burrow, the tip of the tube protrudes out for the entry of water. (*iii*) *Mandible.* In this paired appendages, the incisor processes are not serrated like those of prawn but the palp is stout. (*iv*) and (*v*) *First* and *Second maxillae.* Of these two pairs of maxillae, the second maxillae are more prominent and its exo-

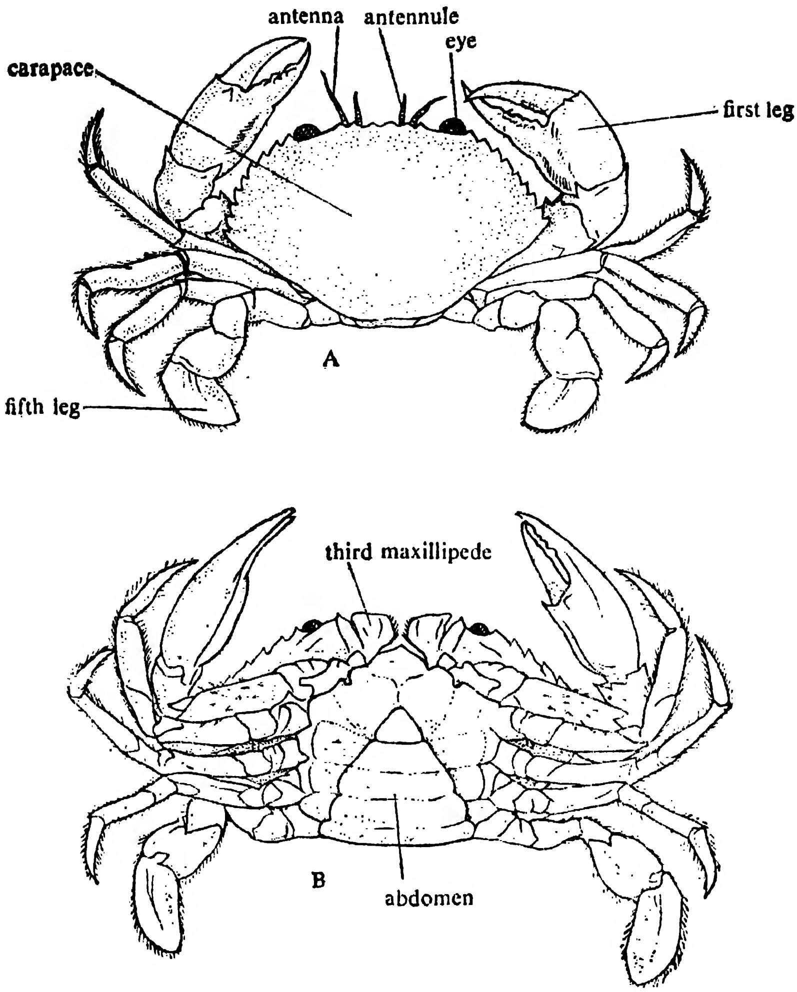


Fig. 16.18. External features of a true crab. A. Dorsal view. B. Ventral view.

podites are developed into scaphognathites in the exhalant passage of the gill chamber. The thoracic appendages are: (*i*) *Maxillipeds*. In all the three pairs of maxillipeds, the exopodites are whip-like and drawn backward to cover the gills. In the second and third maxillipeds, the epipodites are sword-shaped. The basal joint of third maxillipeds are flattened ventrally to cover the anteriorly placed oral appendages.

(*ii*) *Walking legs*. The walking legs are uniramous and jointed. The notable feature in a crab is that the bases of walking legs on each side are set apart. Among the five pairs of walking legs, the first pair is well-developed and is provided with powerful chela. The other legs are clawed but not chelated. The first leg is used for food capture and defence, while the rest of legs are meant for walking sideways.

Abdomen

The abdomen is six segmented, flap-like and much thinner in comparison to the cephalothorax. It remains flexed in the ventral side of the cephalothorax within a groove formed by sternites. The *abdominal appendages* or *pleopods* are rudimentary. Sixth pair of pleopods is absent in both the sexes. Two pairs of *copulatory stylets* formed by 1st and 2nd pleopods are seen in the males. In females, four pairs of pleopods form an egg carrying basket. Thus in a crab, well-developed locomotor appendages like swimmerets of prawn are not seen in the abdomen. *Anus* is present at the terminal end of last abdominal segment.

Digestive system

The alimentary canal begins from mouth and consists of following parts—*oesophagus*, *gizzard* and *intestine* (Fig. 16.20A). The oesophagus is short but the gizzard is quite conspicuous. A pair of *superior caeca* arises from the junction of gizzard and intestine. The intestine runs throughout the entire length of the abdomen and just before entering the abdomen it sends an elongated tube called the *inferior caecum* to the dorsal side. The intestine finally communicates with the exterior through anus which is present in the last abdominal segment. The digestive gland, *hepatopancreas*, is yellowish in colour and infiltrates the fold of carapace. Food is captured by the chelate legs. In case the food is large, the mandibles bite it into pieces before swallowing. The maxillulae and labrum work with mandibular palp to force the food inside the mouth cavity.

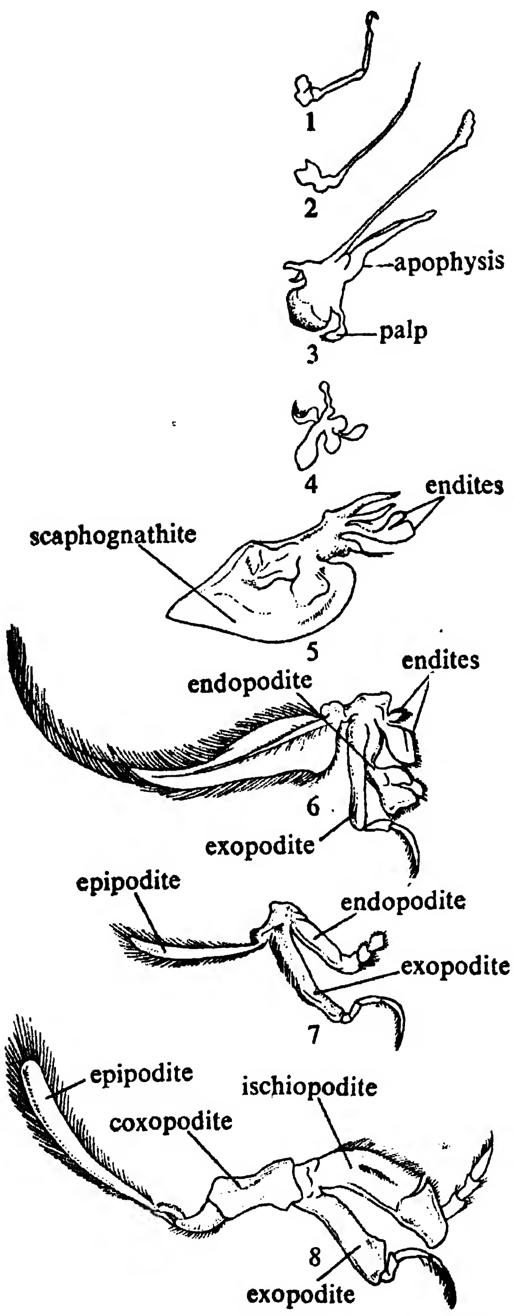


Fig. 16.19. First eight appendages of a true crab (from one side only). 1. Antennule. 2. Second antenna. 3. Mandible. 4. First maxilla. 5. Second maxilla. 6. First maxilliped. 7. Second maxilliped. 8. Third maxilliped.

Circulatory system

Like prawn, the circulatory system is *open type*. *Heart* is irregular in outline and placed within a pericardial sinus in the thoracic chamber. The position of heart is just beneath the carapace and over the reproductive organs which in turn are present dorsal to the intestine. Number of arteries are given from the heart to the different parts of the body (Fig. 16.21). The arteries open within haemocoelomic spaces. The blood contains the pigment haemocyanin.

Respiratory system

The primary respiratory organs are called *gills*, which are arranged like pyramid within the two *gill chambers*. Each gill chamber is present on the side of the thoracic chamber and is completely separated from it by *pleuron*. Externally the gill chamber is covered by the *branchiostegite*. The gill chamber is drawn anteriorly into a tube which opens to the exterior. The water flows within the chamber through the opening in the undersurface of branchiostegite and passes out through the anterior opening. In the crab, *Corystes* sp., an interesting phenomenon is noted regarding the flow of water. When this crab remains within the burrow, the flow of water becomes reverse, i.e. water enters from the anterior end through a tube formed by the antennae and third maxillipeds and exits through the undersurface of the branchiostegites. But when the crab comes out of its burrow, the direction of water flow again becomes same as in other crabs.

Nervous system

The nervous system of crab illustrates extreme instance of fusion which has resulted due to the close approximation of segments (Fig. 16.20B). The *brain* is placed at the anterior end and on the dorsal side. It is formed by the fusion of a pair of *cerebral ganglia.* From the side of each *cerebral ganglion* one *oesophageal connective* arises. These two connectives encircle the gut and unite with the *ventral thoracic ganglionic mass* in the middle of the thorax. These two connectives are joined transversely by a *postoesophageal commissure.* A ganglion is present in the oesophageal connective. The ventral thoracic ganglionic mass is formed by the fusion of *suboesophageal*, *thoracic*, *abdominal ganglia* and major part of the entire *ventral nerve cord.* This mass is perforated by the sternal artery at the middle. From the brain nerves are given off to the eyes, antennae and visceral organs. The

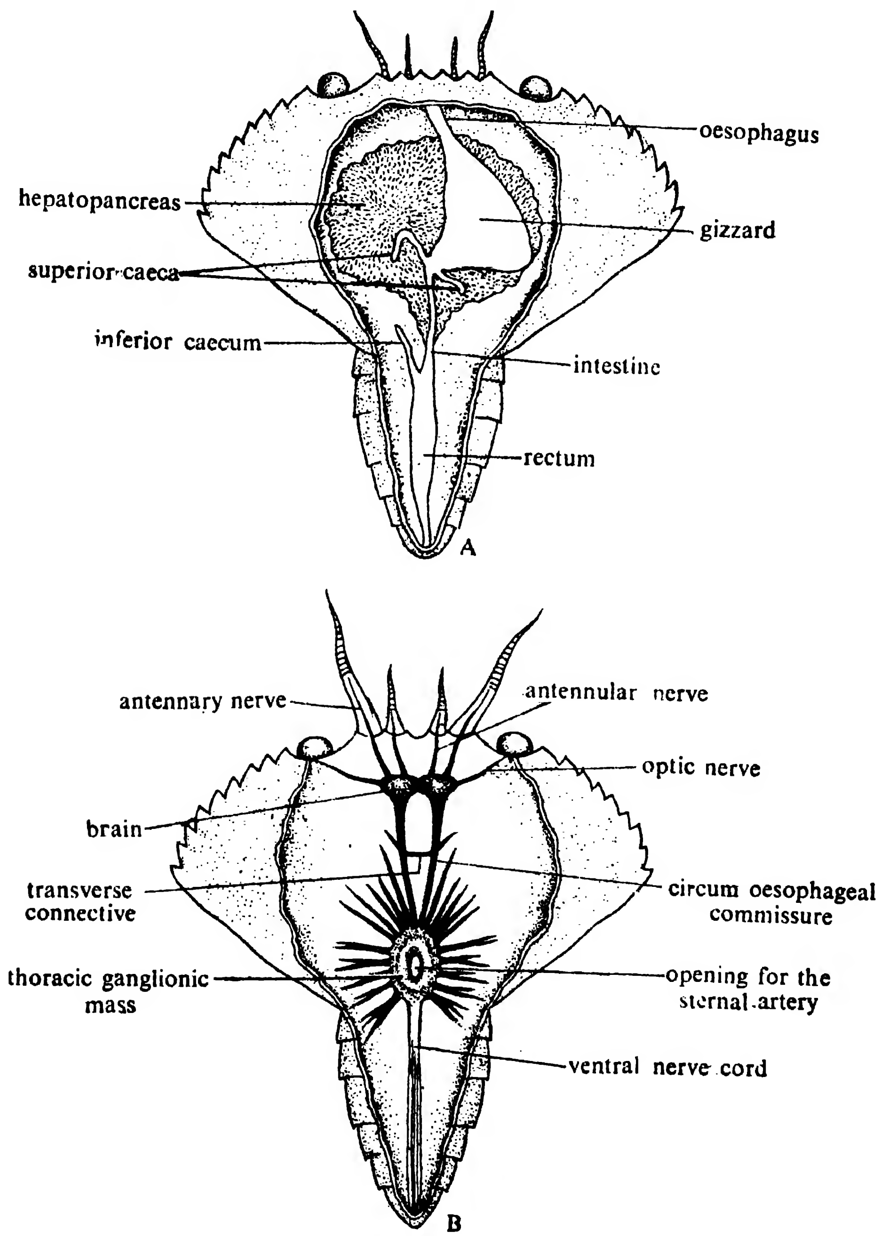


Fig. 16.20. A. Alimentary system of a true crab (dorsal view). B. Nervous system of a true crab (dorsal view). Legs are not drawn in both the figures.

thoracic ganglionic mass innervates maxillae, maxillipeds and thoracic limbs. On the ventral wall of the gizzard along the path of visceral nerve, a small ganglion is present.

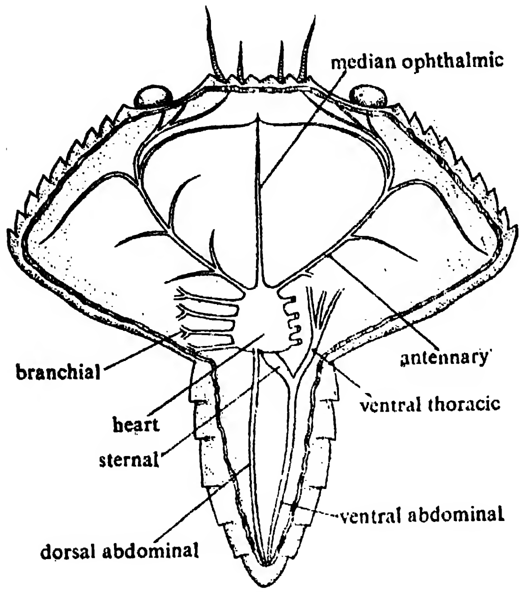


Fig. 16.21. Heart and important blood vessels of a true crab. Branchial vessels of the right side are removed and the legs are not drawn.

Endocrine system

Several endocrine organs are present in crabs. Within each eye stalk and more towards the eye there is an *X-organ*, which contains special neurosecretory cells. At the base of each eye stalk another gland called *sinus gland* is present which acts as reservoir for the hormones liberated by the X-organ. Two other endocrine organs—*Y-organ* in the antennal segment of head and *androgenic organs* along the sperm duct, are epithelial and non-neural in nature. The *postcommissural organ* at the back of the head and *pericardial organ* near the heart, work as reservoir like the sinus gland. The X-organ controls the pigment pattern in the epidermal chromatophores and also influences the action of Y-organ. The Y-organ in one hand regulates moulting and also accelerates the growth of gonads. The Y-organ degenerates after the attainment of maturity. The products from pericardial organ increase the heart beat.

Moulting

The crab is well-known for its ability to shed off the old exoskeleton. Both the external and internal surfaces which are lined by cuticle, throw out the old skeleton and are replaced by new covering. This phenomenon is called moulting and it is necessary for the growth of the individual. The phenomenon of moulting is seen in all arthropods but the process is well understood in crabs.

There are four stages in the entire cycle of moulting, all of which are under hormonal control—(1) *Proecdysis* or *Premoult.* At this stage calcium is removed from the old exoskeleton and the calcium content of the blood increases. A new and soft cuticle is formed beneath the old exoskeleton. (2) *Ecdysis.* It is the stage when the old exoskeleton is thrown out. After throwing out the old skeleton the animal swells up by taking in water and air in its internal spaces. (3) *Metaecdysis* or *Postmoult.* At this phase the new exoskeleton is calcified and hardened. (4) *Intermoult.* This is the stage when the individual is with hard exoskeleton. When young the intermoult period is short but in a full-grown crab the intermoult is terminal or final.

The process of moulting does not arrest the activity of the individual but involves continuous change in its physiology during different stages of moulting. For example, water content, organic reserves, concentration of mineral salts, etc. are seen to alter during moulting. The moulting involves behavioural changes in the crab. The animals hide out at the time of moulting to protect its soft body.

Reproductive system

Sexes are separate and the sexual dimorphism is noted specially in the disposition of abdominal appendages. In male, the first and second pleopods are uniramous and work as *intromittent organ*, i.e. organ for the transfer of sperm within female. In order to do this work, the endopodites of the second pleopods act as a piston within a tube formed by the pleopods of the first. The pleopods in female consist of unisegmented protopodite, each carrying two elongated rami. These rami with their hairy processes form a basket to carry eggs. In both the sexes the reproductive organs are united in the middle and are extended laterally within the fold of the carapace. In male, the reproductive opening is present in the *last leg* and on a flexible process

of the *coxa*. In female, the oviduct of each side is provided with a chamber called *spermatheca* and it opens in *sternum*.

Life history

Fertilization is external and the fertilized eggs are carried by the female in the basket formed by rudimentary abdominal appendages. Development passes through the appearance of three larval stages one after the other. These larval stages are known as *Zoea*, *Metazoea* and *Megalopa*. The transformation from one stage to the next is attained by successive *moulting*. The characters of these larval forms are discussed later together with the various other larval forms in arthropoda. It may be mentioned here that the Zoea larva of crabs has two spines—one at the anterior end and the other at the posterior end of the carapace. The third maxilliped is flattened (excepting *Homolodromia* and related forms, where it is biramous and acts as oar). In Metazoea stage the thoracic limb rudiments appear beneath the carapace and abdominal segments possess pleopods. The Zoea and Metazoea are free-swimming but the Megalopa is able to walk on the substratum.

SOME IMPORTANT CRUSTACEA

HUTCHINSONIELLA. It was first collected in the year 1955 from the beach of Long Island Sound in U.S.A. (Fig. 16.22). Length is 3 mm and its characters are of primitive nature. Eyes are absent. Thorax includes eight segments and each segment carries a pair of legs. All these thoracic appendages and the second maxilla carry gnathobases or endites. Abdominal segments are ten in number and are cylindrical. Abdominal appendages are absent but each segment has pleural spines. Sexes are united (hermaphrodite) but the reproductive organs are different.

BRANCHIPUS. The size is approximately 15–20 cm. These fresh-water, pink-coloured crustaceans are without carapace. Antennules are short but the antennae are long and modified as prehensile organ. Thoracic appendages are flattened and used for swimming. Each thoracic appendage bears gill for respiration. A *shell gland* is present in the cephalic region. Abdomen is distinctly segmented but without appendages. Caudal style is unjointed.

ARTEMIA. It is also known as brine shrimp (Fig. 16.23A). It is noted for its ability to swim on its back. It can tolerate salinity for a considerable period and alteration of salinity produces changes in its structural features. The carapace is absent and the eyes are placed on unjointed stalks. Abdomen usually consists of six segments. Eleven pairs of thoracic appendages are flattened to facilitate swimming. While moving during locomotion these limbs filter the food particles.

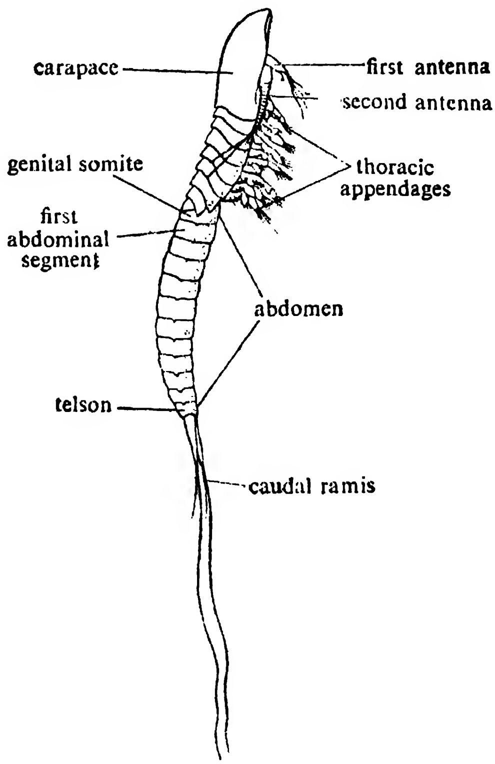


Fig. 16.22. *Hutchinsoniella*, a crustacean with primitive features (after Wilmoth).

Respiration takes place through the general surface of the body and through parts of the appendages. Heart is tubular and provided with several pairs of ostia. Excretory organs include one-shell gland which communicates through the base of second maxilla. Larva passes through *nauplius* stage.

DAPHNIA. Common in fresh-water ponds and pools. The body is laterally compressed and the segmentation is not well marked. A bivalve shell covers the entire body. Prominent biramous antenna and four to six pairs of thoracic legs are used in swimming. Females bear brood pouch.

TRIOPS. In older books it is known as *Apus*. It is a fresh-water form (Fig. 16.23D). Length is 20–30 mm. Anterior two-thirds are enclosed dorsally by carapace. Head is unsegmented, broad and depressed. Abdomen is slender and with distinct segments. A pair of large many-jointed caudal styles extend from last abdominal segment where anus is present. One pair of lateral eyes and a single median eye are placed on the antero-dorsal side of the carapace. An oval structure called dorsal organ is situated posterior to eyes. On each side of the carapace lies a coiled tubular shell gland for excretion. First thoracic appendage is provided with several endites.

maxilla carries a distinct plate and the second maxilla is leg-like. Thoracic appendages are two pairs—first pair is used as leg and the second pair is meant for cleaning. Abdomen is without appendages. Telson is well formed and bears a pair of small caudal styles. Heart is absent. In an allied species, *Pontocypris*, the males having 0·3 mm length produce sperm cells which are as long as six millimeters.

DEROCHEILOCARIS. It was first obtained in the year 1943 from Nebraska beach on Cape Cod (U.S.A.). Length of an adult is 0·4 mm. Biramous mandibles are not specialised. Simple median eye is present. Two pairs of excretory organs (antennal and maxillary) are present.

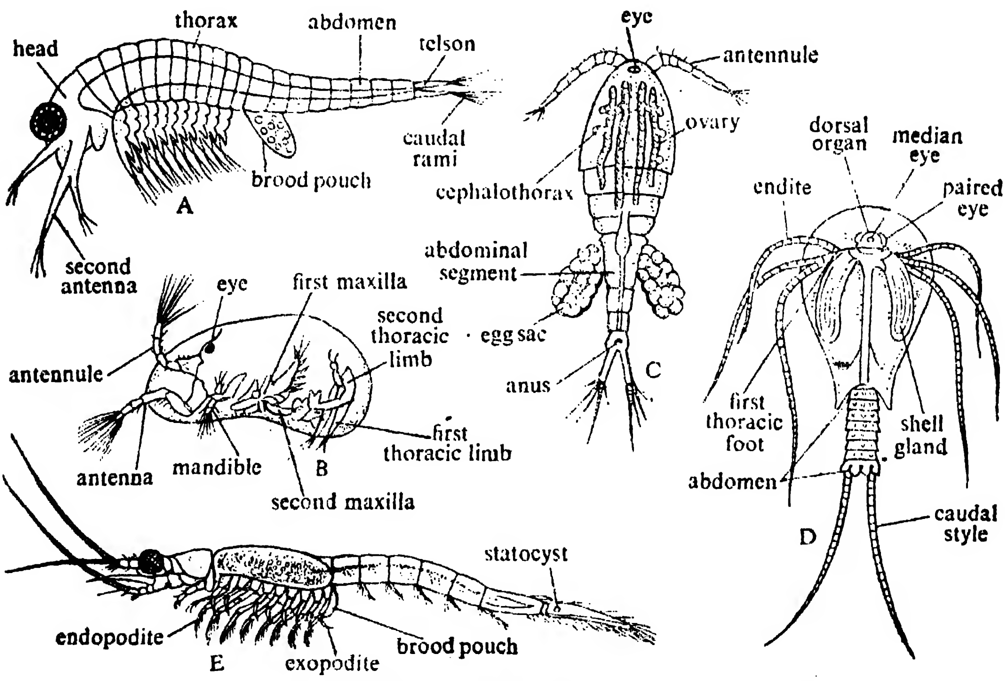


Fig. 16.23. Some important crustaceans. *A. Artemia. B. Cypris. C. Cyclops. D. Triops. E. Mysis* (from various sources).

CYPRIS. These crustaceans are inhabitants of fresh-water and length varies from 1–2 mm (Fig. 16.23B). Unsegmented body is fully covered by a bivalve carapace, the two halves of which are articulated in the mid-dorsal line and inter-connected by a strong adductor muscle. Carapace may be with varied markings. Compound eyes are absent but a simple median eye is present at the anterior end. Appendages are seven pairs. Two pairs of antennae are large and work as swimming organs. First

CYCLOPS. These small elongated and fresh-water forms bear distinct segments (Fig. 16.23C). Movement is rapid and jerky. Females possess egg sacs. Cephalothorax is formed by the fusion of head and first thoracic segment. The carapace projects anteriorly as small rostrum. Remaining five thoracic and four abdominal segments are distinctly visible. A median eye is present on the dorsal side and at the base of the rostrum. Antennules are long and slender. In males, the antennules

bend to form a hook for clasping the female during reproduction. Last thoracic segment carries the genital aperture. The first abdominal segment is fused with the last thoracic segment in females. The last abdominal segment bears anus on the dorsal side. Caudal styles are branched and prominent.

LEPAS. It is commonly known as 'goose barnacle' (Fig. 16.24). The sessile crustacean has a stalk or peduncle on which broad part of the body called the capitulum is placed. The capitulum is covered by carapace or mantle. The carapace is bivalved and consists of five calcareous plates—(*i*) dorsal *carina*, (*ii*) two lower and lateral *scuta* and (*iii*) two lateral and dorsal *terga*. The small vermiform body remains within the shell. In a living specimen, the exo- and endopodites of the six pairs of thoracic appendages peep through the partially opened ventral aperture of the mantle and are engaged in food catching. Antennules are small, but antennae are absent. Two pairs of maxillae are present near the ventral and anteriorly directed mouth. Anterior end of the body is attached with the stalk and the free posterior end terminates as the penis.

BALANUS. These are called rock barnacles or acorn-shells (Fig. 16.24). Stalk is absent in these sessile forms and the body is wrapped by a mantle which is made up of six calcareous pieces. The free end is provided with a lid or operculum which is formed by two plates, *scuta* and *terga*. Six pairs of thoracic appendages extend their delicate processes through the gap beneath the carapace. Strong adductor muscles are present for the movement of carapace. Alimentary canal is 'U'-shaped. Heart and blood vessels are absent. Excretory organs in the adult are called *maxillary glands*.

MYSIS. It is almost like a miniature prawn (Fig. 16.23E). The carapace does not extend up to the last few thoracic segments. Thoracic appendages are uniformly leg-like and carry the exopodites. A brood pouch is present near the posterior thoracic appendages. Pleopods are larger in male than in female. Gills are absent. Eyes are larger in comparison to the body size. Statocysts are distinctly visible at the base of the uropods.

ONISCUS. It is commonly known as wood-louse or saw-bugs. These crustaceans are adapted for land life. Aerial respiration is carried by numerous air-filled tubes. These are small, broad, flattened and more or less oval. Only first thoracic segment participates in the formation of cephalothorax. Compound eyes are sessile. A brood pouch is present.

HOMARUS. It is commonly known as lobster. The body is more or less cylindrical and the chelate legs exhibit symmetry. The exopodites of the uropods bear distinct transverse suture. While moulting the old exoskeleton splits longitudinally along a middle line on the dorsal side. These lobsters are well known for their ability to regenerate lost limbs.

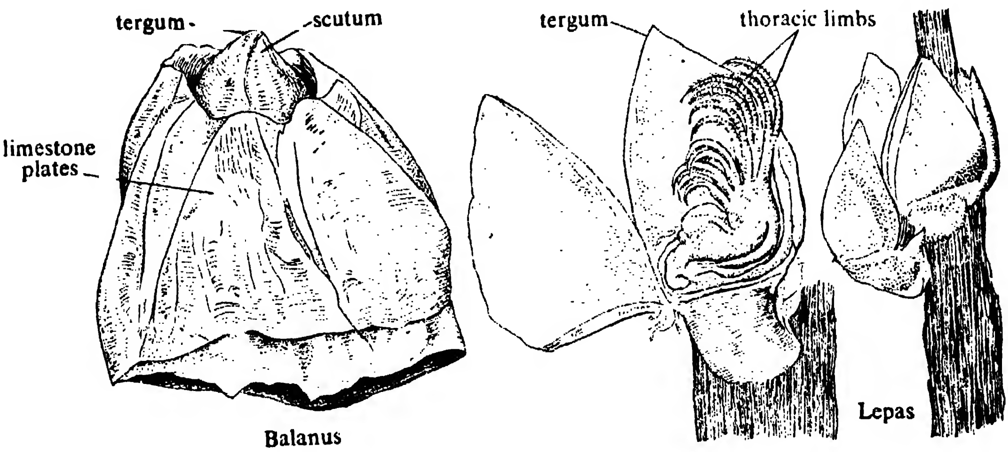


Fig. 16.24. Crustaceans which are sessile. The shell has been opened in one *Lepas* to show the structures.

PALINURUS. This is known as marine rock lobster. The second antenna is long. Rostrum is poorly developed. Legs are not chelated but only clawed. Abdominal appendages are fan-like. The larva is called *Phyllosoma.*

SCYLLARUS. Strongly built broad body is covered with thick spiny exoskeleton (Fig. 16.25). The second antenna is flat and scale-like. The stalked compound eyes are placed in special sockets within the carapace. First pair of pleopods are absent. The telson and uropods are broad and fan-like. The larva is known as *Phyllosoma.*

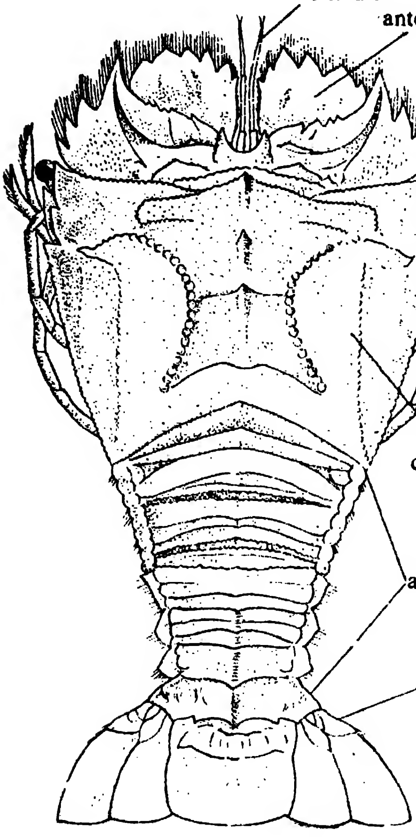


Fig. 16.25. *Scyllarus*—a marine relative of prawn.

EUPAGURUS. The body of Eupagurus or hermit crab is modified for its peculiar mode of life. It always lives within the empty shell of a gastropod (Fig. 16.26A). Cephalothorax is elongated and bears short antennule and long antenna. The soft abdomen remains twisted within the spiral shell of the mollusc. Excepting the uropods, and other abdominal appendages on the right side are absent. Uropod is transformed into a hook-like structure for the attachment within the shell of gastropod. The fourth and fifth pairs of legs are much reduced. The remaining appendages extend out of the shell. First two legs are chelated and the chelate leg on the right side is very large and acts as *lid* or *operculum.* When the growth of the body demands, Eupagurus selects a new large shell and deserts the old one.

HIPPA. It is commonly known as mole-crab (Fig. 16.26B). The body is more or less cylindrical and resembles the true-crabs in having abdomen flexed beneath the cephalothorax. The oval carapace does not extend up to the anterior part, where antennae and small eyes are present. Thoracic and abdominal appendages are modified for the purpose of digging.

GAMMARUS. This laterally flattened fresh-water crustacean is commonly called 'sand flea' and is well known for its ability to dart (Fig. 16.27A). Cephalothorax is formed by the fusion of head and one thoracic segment. The carapace is absent. First antenna is narrow. Mandibular palp is three-jointed. Thoracic appendages are seven pairs—first two pairs are partially chelated, next two pairs are pointed anteriorly and the last three pairs are posteriorly pointed. The base of thoracic leg is plate-like and a gill is attached with each thoracic leg. Abdomen is well-developed and six-segmented. Each of the first three abdominal segments bears a pair of appendages for swimming and producing water current to bathe the gills. The last three pairs of abdominal appendages are posteriorly directed and known as uropods. The uropods are used for darting.

CAPRELLA. These slender and elongated crustacea resemble the stick insect and exhibit perfect mimicry (Fig. 16.27B). The cephalothorax is formed by the fusion of head and first two thoracic segments. The second antenna is smaller than the first. The third thoracic limb is the largest. The fourth and fifth thoracic legs are absent and these segments bear only the gills. Last three segments carry usual types of legs. The abdomen is rudimentary and persists as a small wart at the end of last thoracic segment. Some extent of hermaphroditism is noted in these forms.

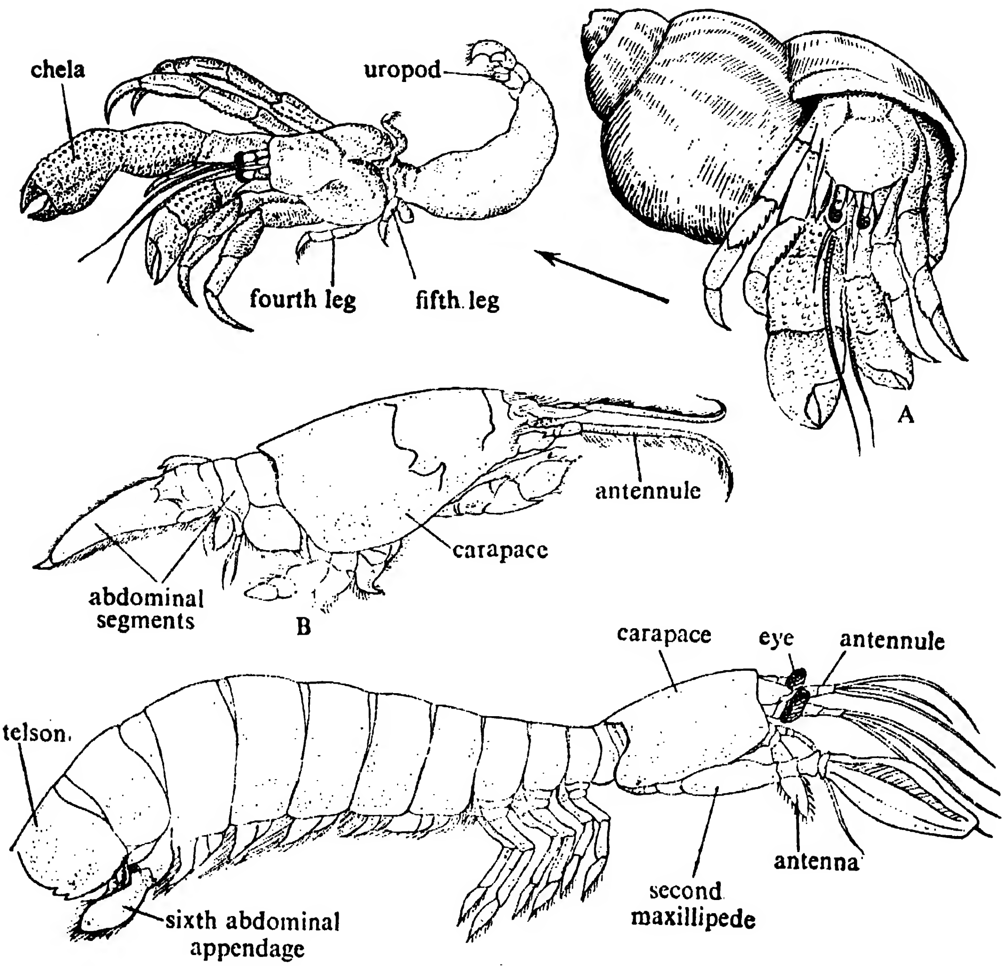


Fig. 16.26. Some important crustaceans (contd.) A. *Eupagurus*. B. *Hippa*. C. *Squilla*. Arrow indicates the body of *Eupagurus* outside the molluscan shell.

SQUILLA. The notable feature of this crustacea is that the abdomen is much longer than cephalothorax (Fig. 16.26C). Carapace does not cover the last three thoracic segments. Rostrum is movable. Head has two movable segments in front —one segment carries the stalked eyes and the other bears the triflagellate antennules. First five pairs of thoracic appendages are uniramous and work as maxillipeds. The second pair of maxillipeds is large and spinny. Pleopods carry the gills.

PARASITIC CRUSTACEANS

Many crustaceans live as parasites on other animals. The hosts include wide variety of animals ranging from other crustaceans to giant whale. The degree of parasitism also varies. Some are temporary, some are permanent; certain forms live as ectoparasites while several others are endoparasites. A brief account of certain parasitic crustaceans (Figs. 16.28 and 16.29) is given below:

MONSTRILLA. The adult of this crustacea is free-swimming. The larva is free-swimming in the beginning but after a short period it pierces the epidermis of a polychaete worm (*Salmacina*) and clings with the help of mandibular hooks. Gradually the larva enters within the body of the host worm and finally settles within the ventral blood vessel. From the beginning of its life the larva does not possess any alimentary canal and at the time of its journey through the body of the host it loses all the structural details and turns into a loose mass of cells. These cells remain within a chitinous covering. Further development of adult structure occurs

from these cells. The second antenna acts as a structure for absorbing nourishment. When full-grown, the adult breaks the body of the host and becomes free-swimming. The second antenna is left within the body of the host. In the adult the appendages are a pair of antennules and several biramous thoracic legs. The thoracic appendages are used as swimming organs. No functional mouth parts are seen in the adult and the alimentary canal includes a mouth leading into a blind short stomach. It has been observed that if more than one Monstrilla infect a worm all become males. Otherwise in the case of a single infection, it may be either a male or a female.

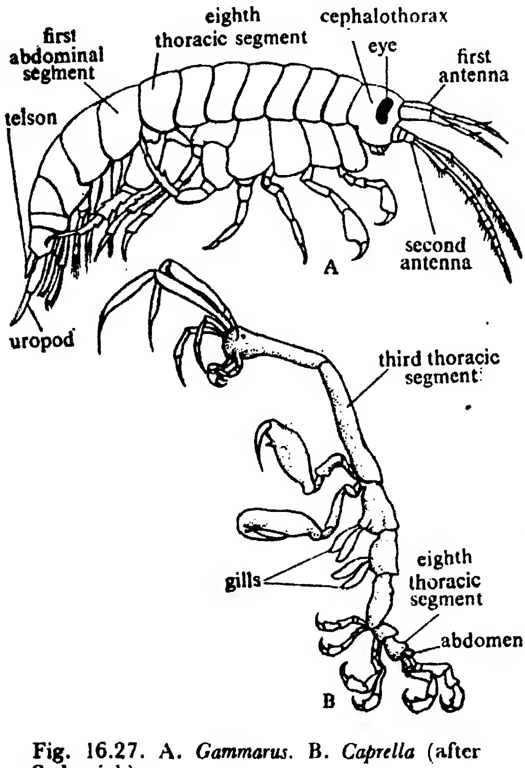


Fig. 16.27. A. *Gammarus*. B. *Caprella* (after Sedgwick).

NOTODELPHYS. Both the sexes infect the gill chambers of Ascidians (lower chordate), but are capable of coming out to lead a free-swimming life. Thus parasitism encountered here is of temporary nature. First antenna is different in male and female. Second antennae are prehensile. In another closely related genus, *Dropygus* the females are fixed with the body of the host and thus are unable to swim.

ASTEROCHERES. It lives as ectoparasite in various animals, i.e. spon ges, echinoderms and ascidia. Excepting the presence of a siphon, practically no structural changes have occurred due to parasitic mode of life. Siphon is formed by the oral appendages and contains three elongated grooves. Styliform mandibles work in the outer grooves of the siphon.

NICOTHOE. It is a parasite on the gills of the lobster. Body is poorly segmented and deformed. Antennae and mouth parts are modified for suction. First antenna is made up of more than seven joints. Thorax is produced into huge lobes but abdomen is of normal size. Paired egg-sacs are present.

LICHOMOLGUS. One species (*L. agilis*) is a temporary parasite on the gills of *Doris* (mollusc). The anterior end is semi-circular and last five thoracic segments are distinct. Size of the thoracic segments gradually reduces from anterior to posterior direction. First abdominal segment is the largest. Caudal styles are well marked.

ANTHOSOMA. It lives as parasite in the mouth of Porbeagle shark. The elongated body is to some extent cylindrical. Antennule is many-jointed. Second antenna is chelate-like. Pleopods are reduced and eyes are absent. Body is modified to form overlapping lobes and possesses paired egg-sacs.

ERGASILUS. It lives as parasite on the gills of a fish called Bass (*Morone* sp.) The body is cylindrical and the segments are distinct. The antennule is five-jointed and the antenna is transformed into a hook-like structure for holding the body of the host. The maxillipeds are prehensile and eyes are absent. Paired egg-sacs are present.

BOMOLOCHUS. It is an ectoparasite on certain fishes, either on skin (in Sole) or in the nostrils (in Cod). First antennules are small but joints are distinct. Second antennae are curved. Maxilliped is well-formed. No siphon is present. First thoracic appendage is modified. Abdominal segment rarely contains any significant appendages.

CHONDROCANTHUS. Females are parasites on the gills and mouths of different marine fishes. It has depressed and

unsegmented body with crinkled lobes. Antennae are modified into hook-like structures for attachment. Mandibles, maxillae and two pairs of thoracic legs are present. Males remain attached to the body of the female and are much smaller.

PHILICHTHYS. These are ectoparasites on the skin of certain teleostean fishes (Sole) and remain fixed near the lateral line of the fish. It exhibits sexual dimorphism—females having long finger-like processes but males are normal. Siphon is absent. They feed on mucus from the slime glands of fishes.

GIARDELLA. Only the adults are ectoparasites on the decapod crustaceans. The lips around the mouth form a hollow projection, but it is not the true siphon, which is present in some crustacean parasites.

CALIGUS. It is an ectoparasite on fish, infecting the gill chamber. Antennules are provided with bristles. Antennae are hook-like. Oral appendages around mouth form a definite siphon, within which the mandible works. Fifth thoracic appendage is long. Females are slightly larger than males and sometimes bear a pair of elongated egg sacs.

LERNAEA. Only female members are parasites. These parasites with vermiform bodies live in the skin and blood vessels of different fishes. A peculiarly lobed anterior end possesses maxillae for piercing. Minute vestiges of feet are present.

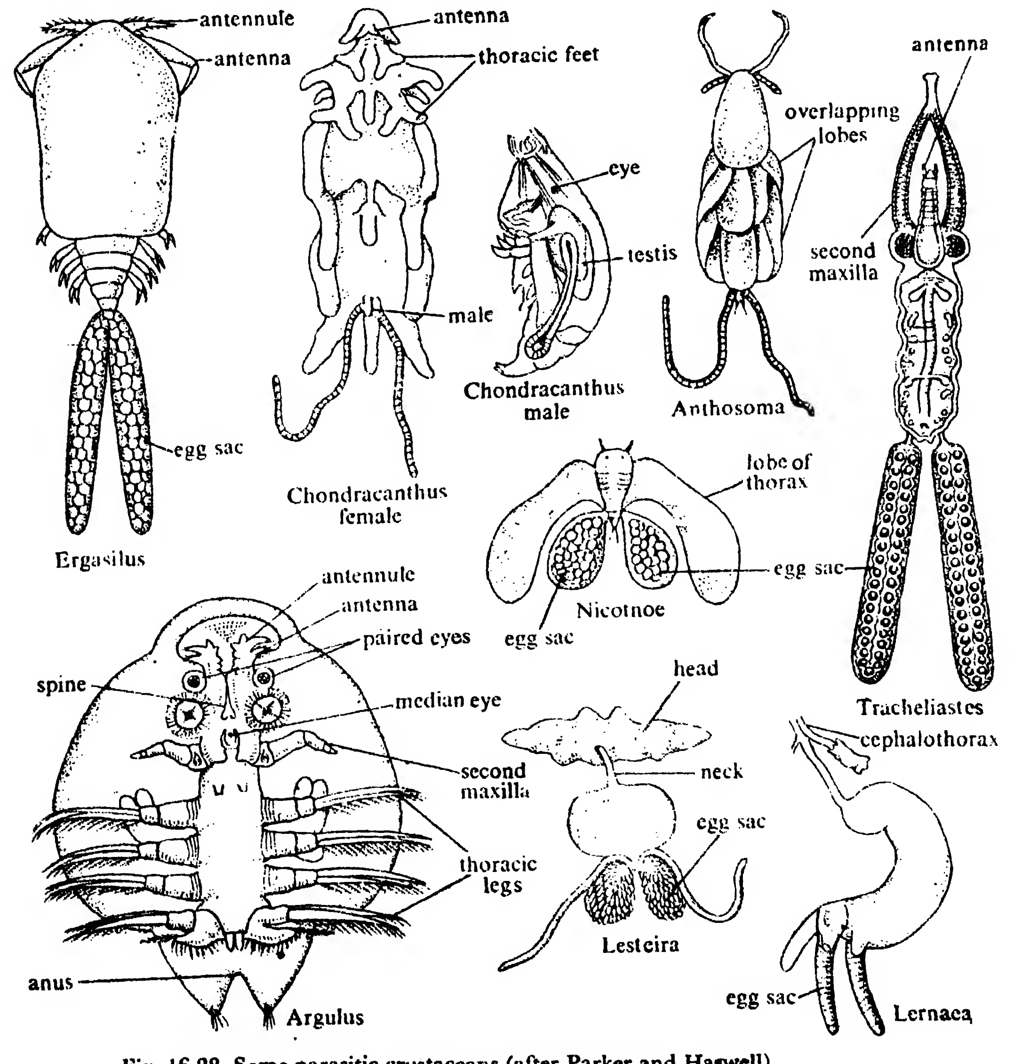


Fig. 16.28. Some parasitic crustaceans (after Parker and Haswell)

Both the sexes remain free-swimming at the beginning. After reproduction, the female becomes parasite and undergoes degenerative changes.

LESTEIRA. These are parasites on fishes and have unsegmented body. The head is swollen and bears suctorial mouth parts. Appendages are reduced and the egg sacs are filamentous.

TRACHELIASTES. These endoparasites of annelids have elongated and segmented body which bears serrated mandibles and within the marsupium of another group of crustaceans belonging to the family Gammaridae. Both sexes reside within the same marsupium. Both the sexes have similar appearance, only the males possess a median glandular thread for its attachment with the female body or with the body of the host. Females are more sluggish than males.

ARGULUS. It lives as an ectoparasite within the gill chamber of fresh-water fishes. It does not remain permanently fixed and either swims freely or crawls over

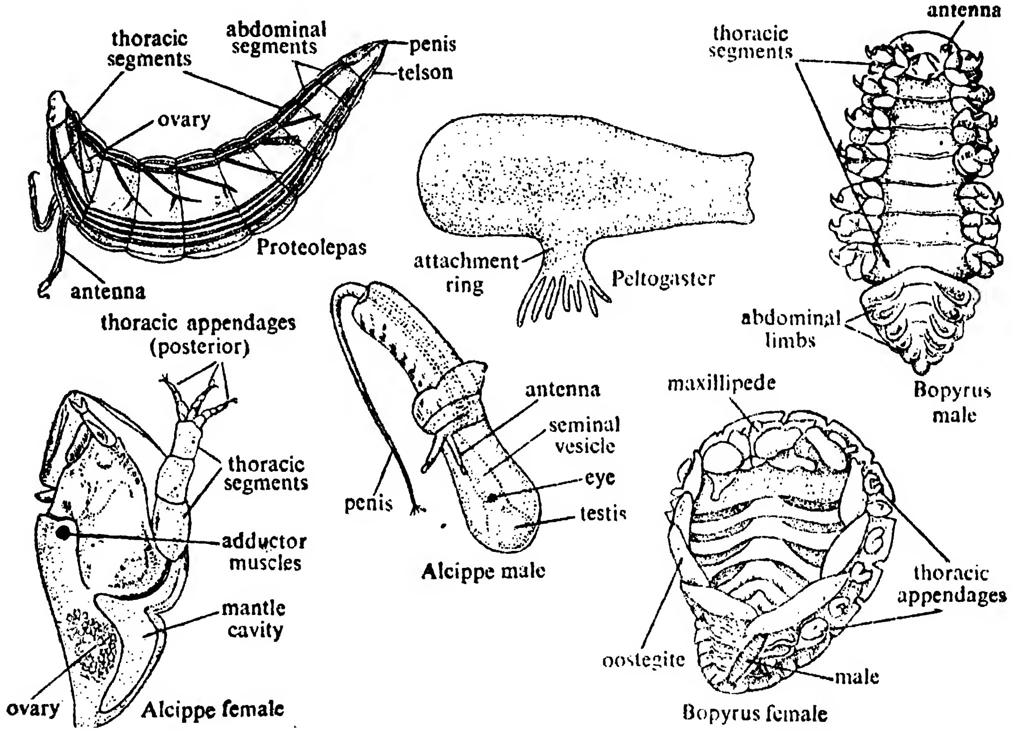


Fig. 16.29. Some parasitic crustaceans (contd.).

uniramous maxillipeds. Second maxillae are enlarged for attachment.

ACHTHERES. The male is smaller than the female. First antennulae are short but similar in both the sexes. In the female, the segments are indistinct. Maxillipeds are fused at their free end with a pad which is beset with chitinous hooks. In males, the posterior segments are distinct and the prehensile maxillipeds are not united. Both the sexes cling to the gills of fishes (Perch, Trout) and live as ectoparasites.

STENOCHOTHERES. It lives as parasite

the surface of the host body. The leaf-like body includes a flat and oval cephalothorax and a small bilobed abdomen. Two compound eyes are distinctly visible and near each eye two short antennae are present. Short first maxillae and styliform mandibles work inside a siphon which together with a poison spine in front acts as the piercing organ. The second maxillae are transformed as suckers. The maxillipeds are modified for clasping and four pairs of thoracic legs are swimming appendages. Breeding takes place outside the body of the host and fertilization is internal.

ALCIPPE. It resides as parasite in the shell of a kind of snail, called Whelk. The thoracic appendages are absent but abdominal appendages are present.

LAURA. These bean-shaped crustaceans are parasites within the cnidarians (Black corals, *Gerardia* sp.). The body is placed within a soft mantle and consists of eleven segments. The thoracic appendages are modified. It is hermaphrodite.

PROTEOLEPAS. These parasites with maggot-like segmented bodies infect another cirripedian crustacea (*Alepas*). It was first collected and described by Charles Darwin but was never found again. The number of segments are eleven of which first eight are thoracic segments and the last three are abdominal segments. Antennae are modified for attachment. The mouth and the legs are absent.

GNATHIA. The adults are free-living but do not take any food. The nutrition is provided by the stored food materials which were obtained in the parasitic state of its larval forms. The larvae live as ectoparasites on different fishes. It absorbs so much fluid that it loses its segmentation and becomes completely round. The adults are 1-8 mm in size and exhibit remarkable sexual dimorphism. In females, the body is filled with the enormous ovary but in males the liver is enormous.

CYMOTHOA. These crustaceans are hermaphrodite. The free-swimming youngs are males. After certain period of growth, *Cymothoa* becomes ectoparasite on different fishes and behaves as female. The legs are short and clawed and the mouth parts become modified for piercing.

CYMODOCE. These are temporary ectoparasites and often are regarded as scavenger on decomposing parts of fishes and other animals. Body is broad, flat and in females the mouth parts are reduced. But this degeneration is compensated by the enormous growth of the maxillipeds.

DANALIA. The larval stages are free-swimming. First free-swimming larva is called *Epicaridian larva*. It transforms into another free-swimming larval stage, called *Cryptoniscus*. It contains a pair of prominent testes in the thorax and a rudimentary ovary on the tip of each testis. At the free-swimming stage it acts as a male and fertilizes the female, which remains parasitic on other parasitic crustaceans like Sacculina. After reproduction, the male fixes itself on the host (parasitic crustacea) as a parasite and turns into a female. The body of a full-grown female looks like a sac containing only eggs and growing embryos. Two pairs of spermathecae are present on the ventral side to receive sperm cells.

BOPYRUS. Like *Danalia*, this is also a protandric hermaphrodite, i.e. same individual first behaves as male and then transforms into female. But in this crustacea, after epicaridian and cryptoniscus stages, another larval stage appears which is called *Bopyrus larva*. It acts as male and bears two pairs of rudimentary antennae and eight pairs of thoracic appendages (first pair is insignificant). Four pairs of abdominal appendages act as gills. The male after fertilizing the female, fixes within the wall of the gill chamber of crustaceans like prawn and transforms into female. The female body becomes asymetrical. The maxillipeds grow considerably to cover the antennae and mandibles. The bases of the thoracic appendages become leaf-like and form a brood pouch.

PORTUNION. These are reddish crustaceans and their adult females live as parasites within the thoracic cavity of crabs and related forms. Development passes through epicaridian, cryptoniscus and bopyrus stages. Bopyrus stage after working as male at first fixes on the thoracic wall within the gill chamber of crab. It gradually becomes female and slowly penetrates inside the thoracic cavity of the host. Finally the body of the parasite contains a rudimentary head and abdomen but the thoracic appendages form a distinct brood pouch. The brood pouch communicates with the gill chamber through a minute aperture, which acts as the outlet of fertilized eggs.

CYAMUS. These crustaceans with their biting mouth parts attack the skin of whale. Broad and depressed body is expanded laterally and has three pairs of clawed thoracic appendages. Abdomen is vestigial.

PELTOGASTER. It is an endoparasite and it infects hermit crab. The body has changed considerably due to the parasitic mode of life. The body of the adult remains attached with the body of the host as a bag-like mass. The outer covering of

the mass is a muscular mantle which is fixed with the body of the host by a ring-like muscular fold. Within the mantle there is a mantle cavity, at the inner wall of which lies the visceral mass. The visceral mass primarily contains the reproductive organs, testes and ovaries. The testes are two in number and are tubular. Each testis opens within a vas deferens. The ovaries are also paired and communicate with the exterior through a pair of oviducts. A slender nerve ganglion is present near the opening of the mantle. This opening of the mantle cavity is present at the anterior end and is provided with a sphincter muscle. Segmentation and appendages are absent in the adult mass. Larva is free-swimming and bears distinct crustacean features.

EXAMPLE OF THE PHYLUM ARTHROPODA—*SACCULINA*

Sacculina lives as a parasite on crab. The parasitic habit has caused much degeneracy of different structures in the adult. The different structures like mouth and anus are absent. It is seen like a soft round tumour on the abdomen of the crab. From this tumour numerous branched filaments are ramified in all the parts of the body of the host except the heart and the gills. The adult Sacculina (Sacculina externa) is characterised by loss of segmentation and appendages. All the organ systems are degenerated except the reproductive organs. There is a pair of elongated testes and a pair of ovaries with accessory genital glands, genital atrium and collaterial glands. There is a single nerve ganglion. The adult Sacculina is difficult to recognise as an arthropod. The study of its developmental history justifies its inclusion as a crustacean. The life history of *Sacculina* is extremely interesting (Fig. 16.30). An adult female produces numerous eggs. The mechanism of fertilization is not actually known. There are diverse opinions regarding the process of fertilization. Fertilization in Sacculina, in all probabilities, is internal.

I. **Nauplius larva:** The youngs are hatched from the eggs as free-swimming **Nauplius** larvae. This nauplius larva is more or less triangular in shape and is peculiar in having two frontolateral horns, each containing a pair of gland cells. It has a median eye and three pairs of appendages for swimming. The second and third appendages are devoid of any masticating process. The body terminates posteriorly into caudal furca. The mouth and alimentary canal are absent in the nauplius and it contains numerous germ cells (ova).

II. **Cypris larva:** In course of development the nauplius transforms into a **Cypris** stage after 3 or 4 months. The free-swimming cypris bears a bivalved shell, six pairs of thoracic biramous appendages and numerous germs cells. The abdomen is extremely reduced and is without any appendage. The abdomen is terminated in a pair of *caudal rami*. Single eye persists. A pair of frontolateral glands open near the margin of the valves of the shell. A pair of three-segmented antennules are present. The terminal segment of the antennule bears backwardly curved structure—the organ for attachment. After a period of free-swimming life, the cypris larva attaches itself to the body of the crab by the help of its hook-like antennule.

III. **Kentrogen larva:** It then discards its thoracic appendages with muscles along with the bivalved shell. The contents of the anterior region of the body become detached and are enclosed in a new sac remaining in connection with the antennules which are fixed to the host. The old cuticle is replaced by a new one to enclose the rest of the body like a sac. The body consists merely of a ball of cells. The pointed end of the cuticle of parasite's hook begins to bore the cuticle of the crab. It is then known as **Kentrogen** stage. Within it a chitinous rod known as DART is differentiated. The point of the dart lies within the fixed antennule. When it is fully formed, it forces its way through the cuticle of the host. Through this dart, the contents of the sac consisting of a mass of undifferentiated cells surrounded by an ectodermal layer pass into the body cavity of the crab. The cells of the parasite enter within the body of the crab and are carried by the blood stream into the thoracic cavity.

IV. **Sacculina interna:** There the cells of the parasite multiply leading into a stage called *Sacculina interna*. It then sends slender processes throughout the body of the crab to draw nutrition. The main body of the *Sacculina interna*, as it continues to grow, degenerates the tissues of the host's body wall. Finally the main body of the parasite pushes out as a swelling in the

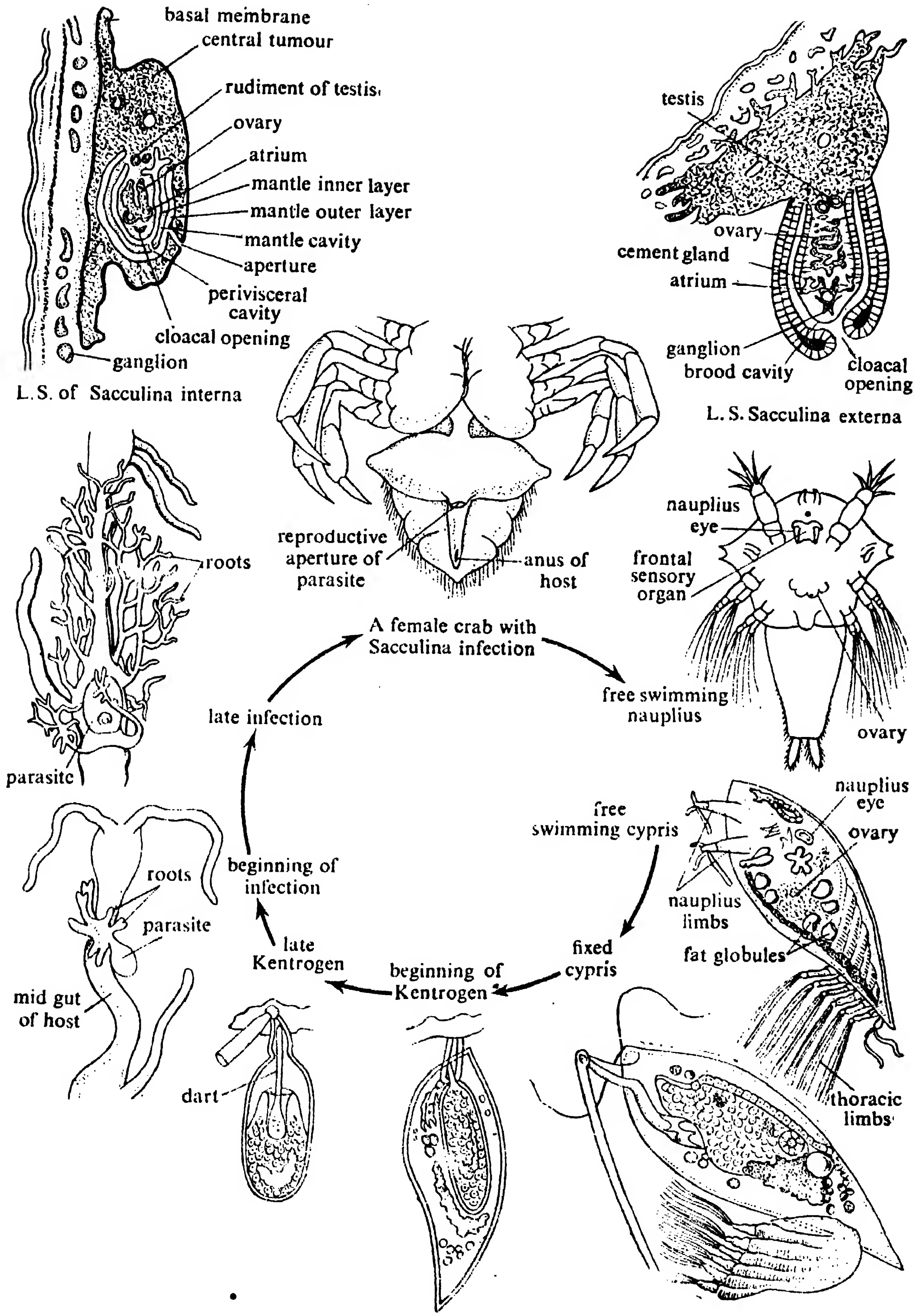


Fig. 16.30. *Sacculina* and its life cycle. Note that the changes due to the parasitic mode of life have attained climax in this crustacea. The adult has lost all the identifying features which are retained only by the free-swimming larva (after Sedgwick).

abdomen of the crab. This phase is called the *Sacculina externa.*

Effects of Parasitism

The parasitic mode of living exerts tremendous effects on the parasite as well as on the host (Fig. 16.31).

On the Host

The host crab shows great disturbance in the metabolic processes. The process of moulting ceases when the parasite becomes external. In both the sexes of the crab, the infection of sacculina inhibits reproductive activities resulting into the atrophy of gonads. The males, in addition, lose distinctive male features, i.e. shapes of the chelate legs. They develop various degrees of secondary sexual characters proper to the females. The chelipeds remain in the form of non-breeding phase. The abdomen becomes more or less flattened and may assume the female form. The copulatory styles are greatly reduced and small pleopods may appear on the third to fifth abdominal pleopods. It has also been reported that a completely modified male, when recovers from the parasitic infection, may be able to regenerate gonads in some cases. Thus the individual becomes hermaphroditic producing both ova and sperms. The female crab, after infection with Sacculina, shows great reduction in the size of the pleopods and the gonads show reduction in size.

On the Parasite

Most of the organs lead to a high degeneration excepting the genital organs and the organ for adhesion.

Impact of parasitic life on crustacea

It is evident from the above-mentioned examples of parasitic crustaceans that

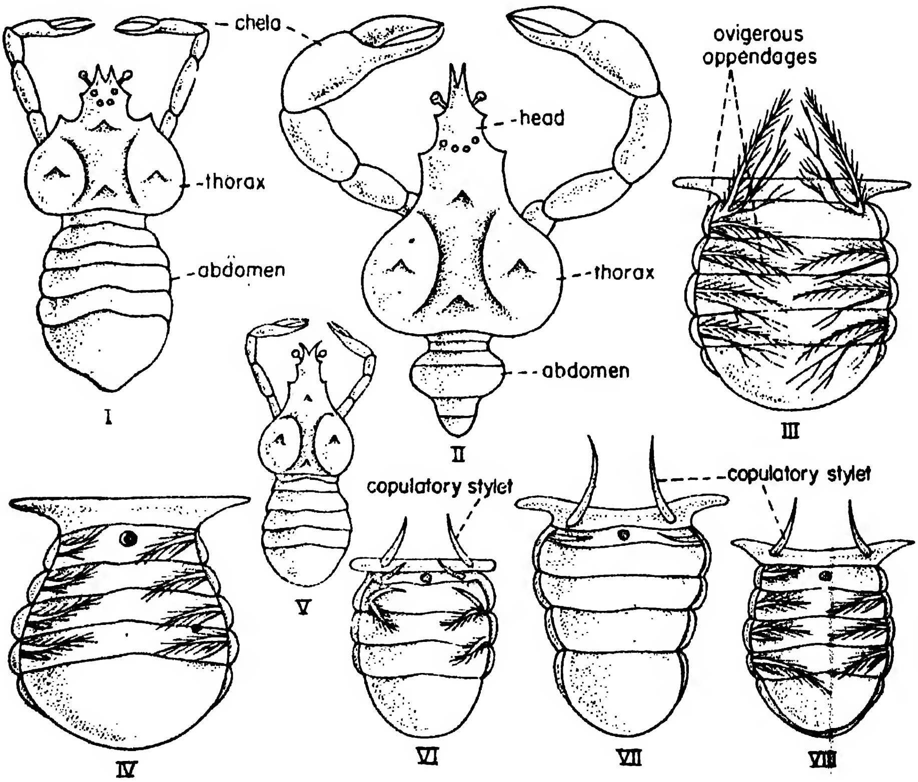


Fig. 16.31. Parasitic effect of *Sacculina* on the sex of host crab. I. Normal non-infected female crab. II. Normal non-infected male crab. III. Abdomen of a normal female. IV. Abdomen of infected female. Note the reduction of ovigerous appendages. V. Infected male crab. Note the reduction of chela and their conversion to feminine chela. VI–VIII showing the abdomen of infected male. Note gradual approximation to feminine condition.

parasitism often involves following changes in the parasites themselves—1. Loss of segmentation. 2. Loss of appendages. 3. Loss of different systems, i.e. alimentary, circulatory and excretory systems. 4. Loss of typical crustacean features and 5. Reduction of metabolic rate. The effects of parasitism increase with the degree of parasitic life. The endoparasites exhibit more degenerative changes than the ectoparasites. In some, like Sacculina, the degeneration is so extreme that only through the study of their larval forms it has been possible to ascertain their systematic position. In spite of these degenerative changes the parasitic crustaceans exhibit suitable mechanisms for holding and piercing the host, for absorbing nutrients and possess efficient reproductive mechanism to help in prolific multiplication and safe dispersal. Thus parasitism not only causes degeneracy but also leads to specialisation. Both are needed for the survival of the individual.

Example of the Phylum Arthropoda—*TRILOBITES*

These groups of arthropods have no living members and are represented only by fossils. Altogether 19 genera are known to have had included nearly 4000 species. A fossil trilobite was first discovered in the year 1698, but was then wrongly identified as the skeletal frame of a flat fish. The trilobites practically have no semblance with the modern arthropods (Fig. 16.32). The actual affinity of trilobites has not yet been conclusively proved, but it is definite that

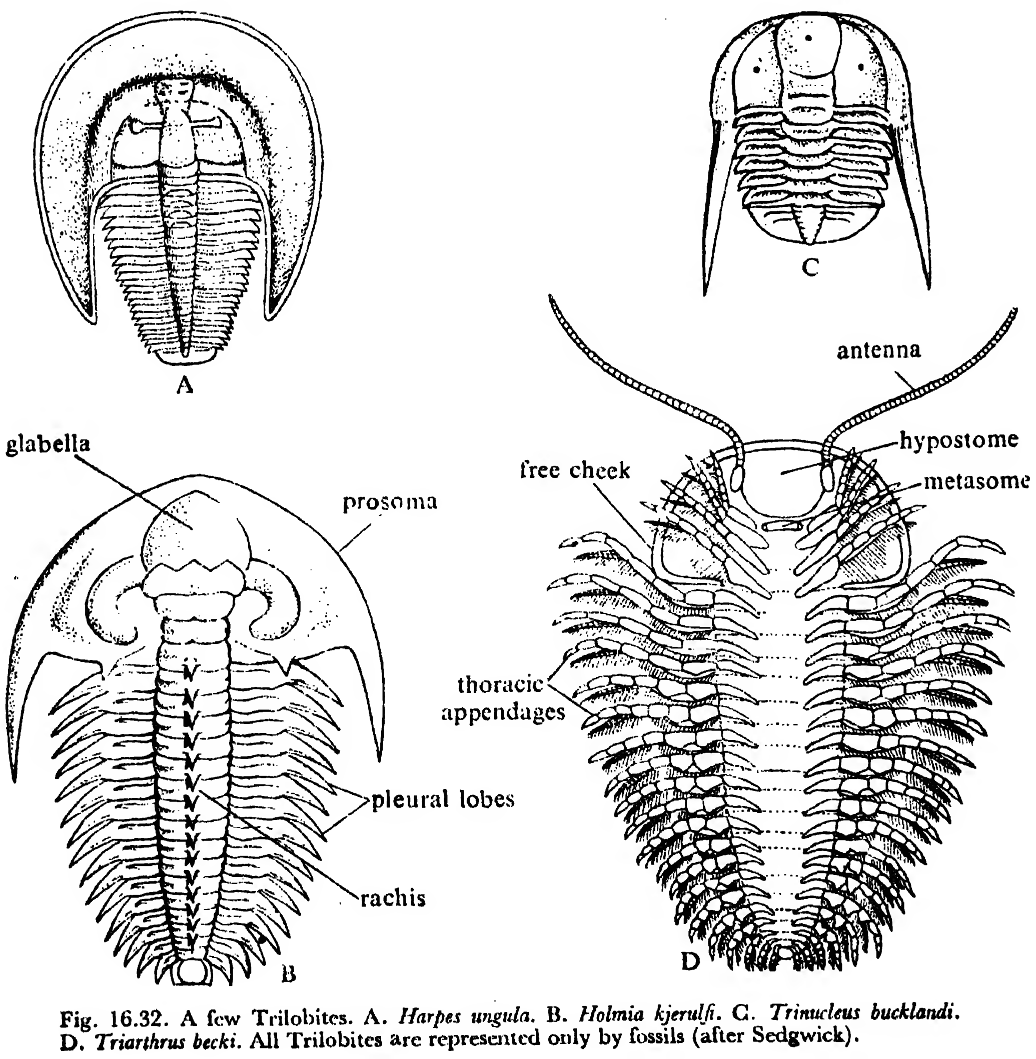


Fig. 16.32. A few Trilobites. A. *Harpes ungula*. B. *Holmia kjerulfi*. C. *Trinucleus bucklandi*. D. *Triarthrus becki*. All Trilobites are represented only by fossils (after Sedgwick).

these fossils, in addition to their specific characters, have features common to arachnids and crustaceans. The trilobites are undoubtedly the oldest arthropods but nothing is known about their origin.

Habit and Habitat

All the trilobites were marine animals as indicated by the fact that their fossils were found from beds which contained the fossils of various other marine animals. The trilobite fossils were found from Pre-cambrian and Cambrian beds and they became extinct before the end of Permian period. These arthropods were believed to crawl in the ocean substratum and were able to swim up to certain height. Nothing is known about their feeding mechanism and other behaviours. The trilobites were distributed throughout the world.

Structure

The size varied from 8 mm of the fossils (*Agnostus*) to 75 cm (*Uralichas*). The body of trilobite was dorso-ventrally flattened and the most distinguishing feature was that two longitudinal lines divided the body into three lobes—*median* or *axial* part in the middle and two *lateral* or *pleural* parts on the sides (Fig. 16.32). Such divisions have given this group the name, trilobita. Like other arthropods, the body of trilobite was divisible into three parts—*head* or *cephalon* or *prosoma*, *thorax* and *abdomen* or *pygidium*. The thorax and abdomen together constituted what is known as *opisthosoma*. The entire exoskeleton was calcareous.

The exoskeleton which enclosed the head region is called *cephalic shield* or *carapace*. The region of carapace enclosing the axial part is called *glabella* and which shields the pleural parts is known as *cheek* or *genae*. The segments of the head region were distinctly recognisable from the impressions of *transverse furrows* on the glabella. The last cephalic segment is called *occipital* or *neck ring* and the furrow which separates it from the thorax is called *neck furrow*. The neck furrow extends within the cheeks of both the sides. The furrows are more prominent in primitive forms than in the comparatively recent types. The cheeks are divided by a longitudinal *facial sutures* into inner *fixed cheeks* and outer *free cheeks*. The carapace bends ventrally to form a rim called *doublure* (Fig. 16.33).

The number of segments in the thoracic region varies from 2 (*Agnostus*) to 26 (*Harpes*). All the thoracic segments are free. The free segments helped the trilobite to coil up. In each thoracic segment the axial part consists of (*a*) broad belt-shaped *ring*, (*b*) a knotched *groove* and (*c*) *articular portion*. The pleural parts of each thoracic segment is bent and divided into (*a*) flat internal part and (*b*) slender external part. The bending of the pleural part is called *falcrum*, which may bear a triangular *facet* for articulating with the preceding segment.

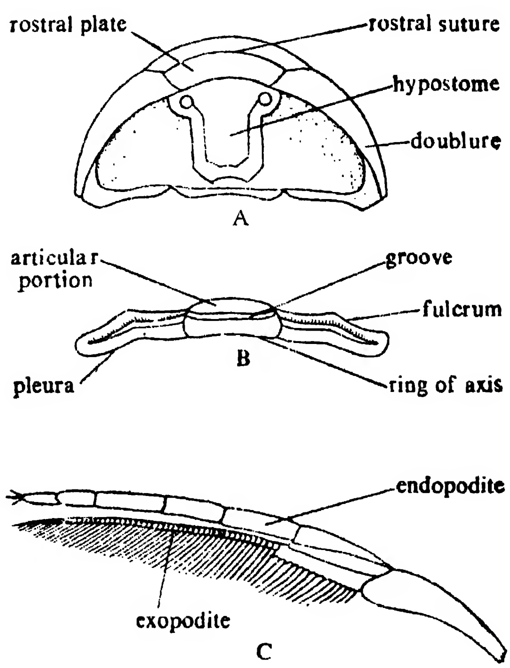


Fig. 16.33. Diagrammatic view of different parts of a Trilobite. A. Ventral side of head. B. One thoracic segment. C. A thoracic appendage (after Sedgwick).

The number of abdominal segments varies from 2–28 and all are fused. The shape of the abdomen is variable in different trilobites. It may be semi-circular, triangular or semi-parabolic.

Following structures are seen in trilobites —*eye*, *labrum* or *hypostome*, *macula*, *mouth* and different *appendages*.

Eye. Some trilobites were without eyes (*Agnostus*, *Microdiscus*). In certain forms, e.g. *Trinucleus*, eyes are simple. But in most a pair of compound eyes are placed on the free cheeks. In most cases, the eyes are sessile but in some immovable stalks are

present. But in all the forms eyes are placed on *palpebral lobes*, which are formed by the parts of free cheeks. Three types of compound eyes are seen in trilobites. (*a*) *Holochroal*. Lenses are closely approximated and are globular or biconvex. The cornea extends over the entire surface of the eye. (*b*) *Prismatic*—smooth cuticle covers the entire surface of the eye. The closely approximated hexagonal lenses are prism-like and plano-convex. (*c*) *Schizochroal*. The carapace separates the biconvex lenses which are circular in outline. The cornea thus does not form a continuous covering over the entire eye. The number of lenses in the eye may be variable. The number of lens increases from young to adult but decreases in the old forms. Within each eye, the lenses remain arranged in alternate rows.

LABRUM OR HYPOSTOME. These are plates which remain attached with the ventral doublure. The shape of the plate may be either square or oval. In *Triarthus*, a lower lip plate or *metastoma* is seen to be present immediately after the hypostome.

MACULA. These are present behind the labrum as a pair of elliptical or oval small patches. In many trilobites, the surface of the maculae are smooth and glossy and in others each macula is surrounded by either an elevated border or pits or tubercles.

MOUTH. The mouth is placed close to the hypostome and where the metastoma is present it lies between it and the hypostome.

APPENDAGES. The structure of appendage is well studied in forms like *Triarthrus*. One pair of appendages are present in each segment excepting the anal segment. The first pair of appendages which are called antenna are uniramous and the rest are biramous. The antennae are placed on the sides of the hypostome. Each antenna has a single flagellum which is composed of numerous conical joints. Each thoracic appendage consists of a small coxa having inwardly directed cylindrical prolongations which form *gnathobases* or *endites*. Both the exo- and endopodites are of same sizes but structures are different. The exopodite has a long proximal joint with serrated edge and a distal part of ten or more joints which have lining of setae along the posterior border. The six-jointed endopodite gradually tapers at the end.

The abdominal appendages are of two types: (*a*) In the anterior part of the body appendages resemble thoracic legs and (*b*) In the posterior part of the appendages are provided with broad and flat endopodites.

Development

The development is known only in few instances. The earliest developmental stage of trilobite is known as *protaspis*. It has a length of 0·4 mm to 1 mm. The shape of protaspis is circular or oval. The cephalon is large with five distinct segments in its axial part. The abdomen is small.

From the examination of fossils of different stages, it has been assumed that development of trilobite (Fig. 16.34) from protaspis stage passed through following changes: (*i*) Modifications in the shape and size of glabella, (*ii*) Number and depth of the furrows in glabella increased, (*iii*) Free cheeks grew in size, (*iv*) Facial suture and eyes moved inwards, (*v*) Number of thoracic segments increased, (*vi*) Size of the head decreased.

Affinity

The trilobites are the oldest of all arthropods and bear a number of primitive characters—1. Presence of innumerable number of thoracic and abdominal segments. 2. Arrangement and nature of appendages. 3. Head region together with its appendages is unspecialised. Two other groups of arthropods—Xiphosura and Crustacea are believed to have some relationship with the trilobites.

AFFINITIES WITH XIPHOSURA

The Xiphosura are chelicerates which include the *Limulus*. Following features are common in both trilobites and Xiphosura: (*i*) Body is divided into three lobes. (*ii*) Cephalothorax bears lateral eyes. (*iii*) Appendages are biramous. (*iv*) Presence of lateral spine in the pleura. (*v*) Larval stage of Limulus resembles the appearance of trilobite and is known as ***trilobite stage***. In spite of these resemblances there are certain points of dissimilarity which speak against such affinity (*i*) Presence of antenna in trilobite. (*ii*) Presence of five pairs of cephalic appendages in trilobite. (*iii*) Thoracic and abdominal appendages are biramous in trilobite. (*iv*) Presence of

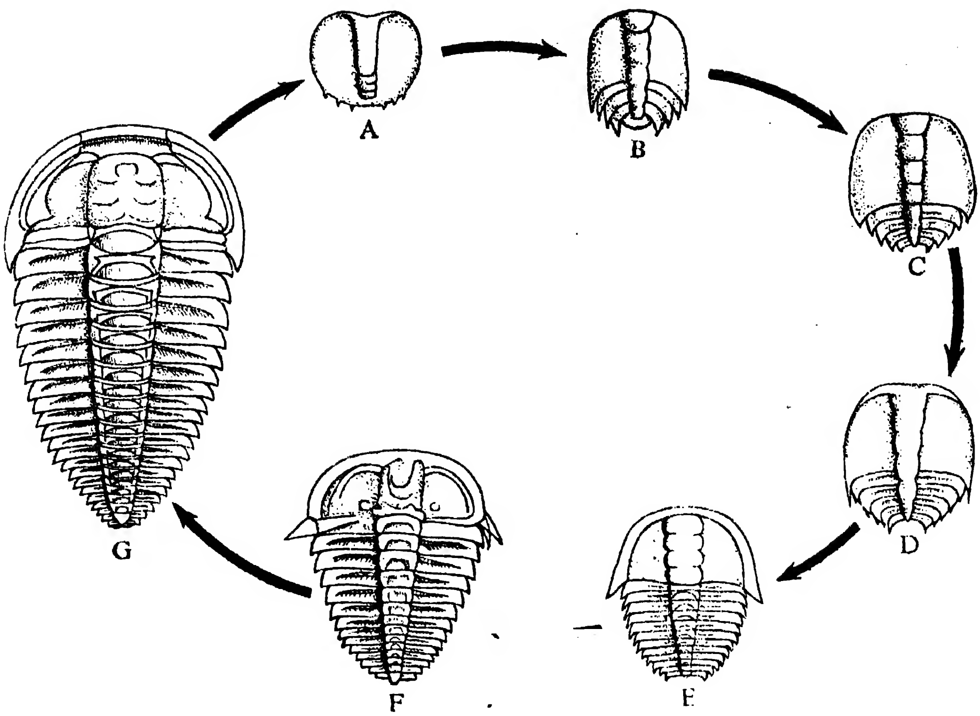


Fig. 16.34. Life history of a Trilobite, based on the fossils at different stages of development. A. Protaspis stage. B–F. Successive stages of development. G. Adult (after Sedgwick).

labrum or hypostome in trilobite. (*v*) No genital operculum is present in trilobite. (*vi*) Protaspis larva of trilobite has no semblance with the Limulus larva.

Affinities with Crustacea

The affinities with crustacea are claimed because a few groups of crustacea like Phyllopoda, Leptostraca, Isopoda were present in the fossil beds where the trilobites were found.

Relationship with phyllopoda. This group includes crustaceans like *Triops* (*Apus*) and *Branchipus*. The trilobites resemble these forms on following features. (*i*) Presence of several variable trunk segments. (*ii*) Presence of a prominent labrum. (*iii*) Presence of gnathobases or endites on thoracic appendages. (*iv*) Presence of a single pair of antennae resembles certain kinds of *Triops*, where second pair of antennae are rudimentary. But the trilobites differ from the phyllopods in having (*i*) Less specialised cephalic appendages. (*ii*) All appendages, excepting antennae are biramous. (*iii*) Eyes are present on free cheeks, (*iv*) Abdominal segments are fused. (*v*) All abdominal segments bear appendages. (*vi*) Body is distinctly divided into axial and pleural lobes.

Relationship with leptostraca. This group includes forms like *Nebalia*, *Paranebalia*. Trilobites resemble these crustaceans in following features: (*i*) Segments are of same number (specially a trilobite, called *Holmia* resembles the *Nebalia*. (*ii*) Less specialised nature of maxillae and mandibles. (*iii*) Structure of thoracic legs resemble the *Paranebalia* in having long exo- and endopodites.

Relationship with isopods. The trilobites resemble these groups of crustaceans in following features: (*i*) Body in both is dorso-ventrally flattened. (*ii*) Body is divided into three regions—head, thorax and abdomen. (*iii*) Eyes are sessile. In spite of these similarities, the structure of thoracic segments and construction of appendages differ markedly in the two groups.

It is evident that the primitive features of trilobites are not seen in Xiphosura and Crustacea. For this reason, the trilobites are regarded as a completely separate group. But fossil evidences indicate that

some Phyllopod crustaceans occurred at the same time when trilobites flourished. Structural resemblances with the phyllopods also speak about the existence of ancestral connections.

EXAMPLE OF THE PHYLUM ARTHROPODA—*SCOLOPENDRA*

Habit and Habitat

The common Indian Scolopendra is scientifically known as *Scolopendra amazonica*. The other Indian species are *Scolopendra morsitans*, *Scolopendra valida*, *Scolopendra hardwickei*, *Scolopendra mazbii* and *Scolopendra subspinipes*. These elongated animals are photonegative and live in darkness. Specially the burrows, crevices, logs of wood and fallen leaves are its favourite abode. It is a swiftly moving animal and prefers to stay in damp places. Scolopendra cannot stand temperature over 40°C.

External structures

The elongated and dorso-ventrally flattened body is clearly divisible into a small *head* and a long *trunk* (Fig. 16.35). The body is covered by cuticular coating which is frequently shed off. These exoskeletal coverings are comprised of numerous plates having varied appearances. These are known as *sclerites*. The *arthroidal membranes* connect these sclerites and allow limited free movement. The dorsal part is deep red and the ventral portion is yellowish in colour.

HEAD. The head may be separated into *cephalic capsule*, *cephalic lobes* and *cephalic appendages* (Fig. 16.35). The cephalic capsule is enclosed dorsally by a *cephalic plate* and by several sclerites in ventral, lateral and anterior sides. It looks more or less circular from the dorsal side and triangular ventrally. Anteriorly, the capsule of the head bears a pair of *antennae* which are many-jointed and set apart. Immediately behind antennae, on each antero-dorsal side two pairs of simple *eyes* are present. The cephalic or head lobe is divisible into *labrum* and *hypopharynx*. These two, together with following appendages constitute the mouth parts (Fig 16.36): (*i*) a pair of horizontally placed *mandibles* with five teeth and bristles at their free end and (*ii*) two pairs of *maxillae*. The small first maxillae are fused with labium-like structure and consisting of two segmented palp and massive coxae. The basal pieces or coxae of the second maxilla unite with its fellow from

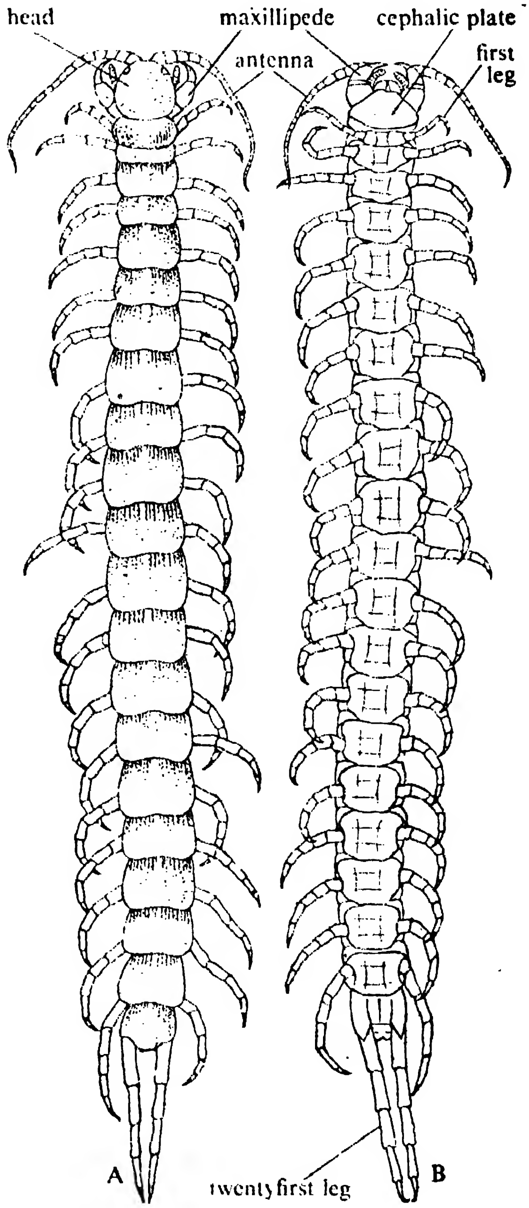


Fig. 16.35. External features of *Scolopendra*. A. Dorsal view. B. Ventral View.

the corresponding side to constitute lower lip. The remaining part of the second maxilla forms a three-jointed leg-like palp with claw at the terminal end.

In addition to these appendages maxillipeds of first trunk segment work as mouth

part. It is to be noted that the head of embryonic scolopendra is metamerically segmented, which fuse in the adult.

TRUNK. The trunk is divided into twenty-four identical segments. The first abdominal segment is closely apposed with head and bears a pair of appendages called maxillipeds or poison claws or toxicognaths. Each maxilliped is made up of five pieces of which the terminal one bears a sharp claw through which opens the poison gland. The next twenty-one segments (2nd–22nd) bear in each a pair of legs. Each leg is seven jointed (though five are distinctly visible) and terminated with a claw having two ventral spines. The legs gradually increase in size from anterior to posterior. The pair of legs in the 22nd segment which is called *anal leg* are longer than the remaining legs. In males, this difference is well marked. The body is terminated by a piece which is not regarded as true segment. It is known as *telson* and it bears an aperture, the *anus*. In between 22nd segment and telson, the 23rd and 24th segments have taken part in the making of *external genitalia*. In males, the genital segment is provided with a pair of projections known as *genital styles*.

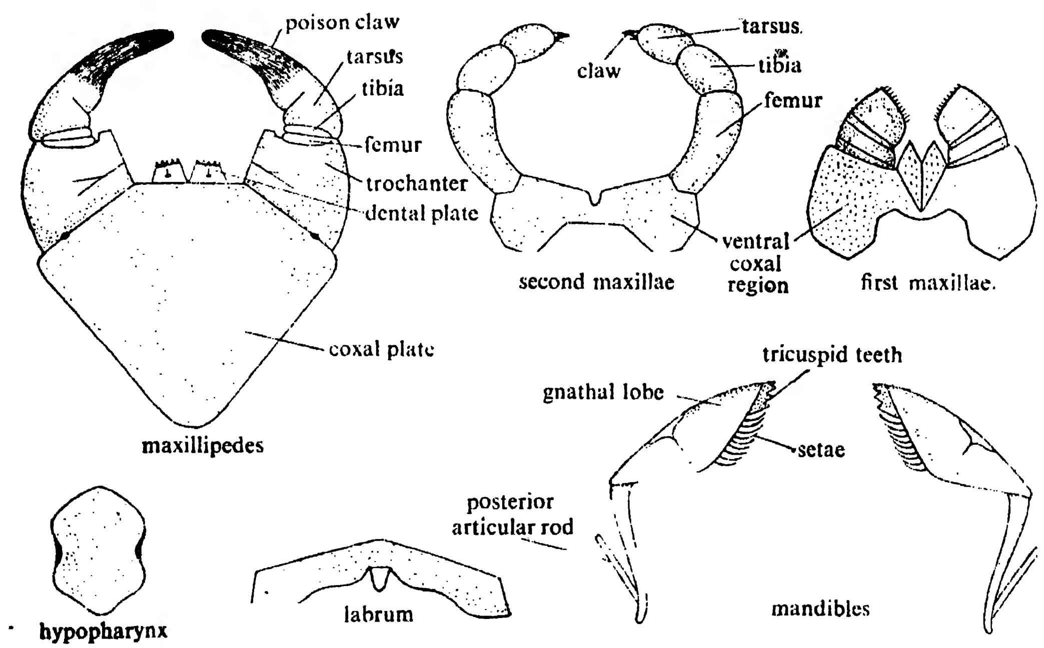


Fig. 16.36. Mouth parts of *Scolopendra*. Ventral view (after Jangi).

Integumentary system

The integument is composed of (1) two-layered *cuticle*, (2) monolayered ***hypodermis*** and (3) non-cellular ***basement membrane***. The absence of waxy coating over the cuticle causes rapid loss of water in Scolopendra. For this reason, these animals prefer to stay in damp places and drink water regularly. Both unicellular and multicellular glands are seen to be associated with the integument. The unicellular integumentary gland cells are scattered in the hypodermis and they produce a lipoid material to cover the external part. The *poison gland* in the maxilliped is a kind of unicellular gland. Here the cylindrical sac-like body of the gland is lined by numerous unicellular glands. (Fig. 16.37). These glands produce a yellowish, acidic fluid, which ultimately passes through a highly cuticularised duct to open in the centre of maxilliped claw. The secretion of poison gland is believed to have three functions—offensive, digestive and partially lubricating.

Following multicellular glands are seen in scolopendra:

A. GLANDS OPENING IN THE HEAD REGION. The glands mentioned below are primarily concerned with digestion. These

are called *salivary glands*. Their products are also believed to be used as cleansing fluid, and act as fungicide.

(1) Epipharyngeal glands. These glands are two pairs and are placed beneath the brain. Anterior pair is larger and

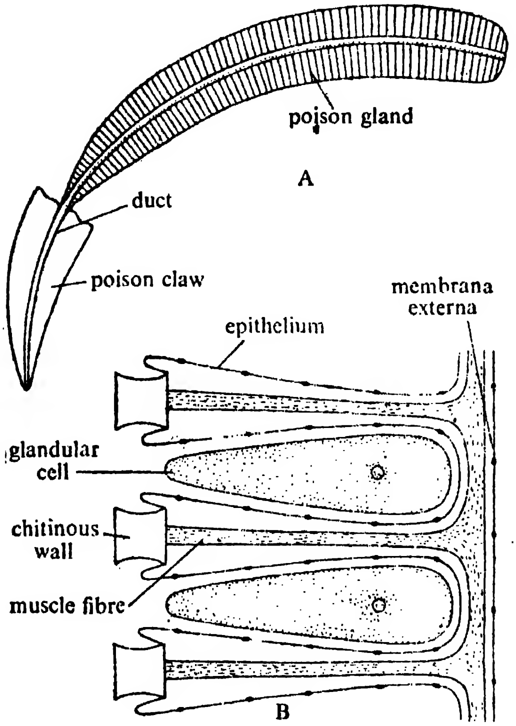


Fig. 16.37. A. Poison gland of *Scolopendra* with poison claw. B. Histological structure of poison gland (Diagrammatic) (after Jangi).

communicates laterally with each other. The outlets of their ducts are placed in epipharyngeal surface.

(2) Labial glands. These are seen as a pair of prominent lobular glands in the space between fifth and seventh segments. Their products are collected by numerous small ducts, which in turn unite to form a common duct and extend anteriorly along the alimentary tube. It finally opens to the exterior through the ventral surface of the head and between the hypopharynx and labium.

(3) Maxillary glands. One pair of these glands are present in the third and fourth segments. These glands, excepting their sizes, closely resemble the labial glands. Their ducts open near the second maxillae at the ventral side of head region.

B. Glands opening in the trunk region. Exact functions of these glands mentioned below are not known:

(1) Coxal gland. One pair of this gland begins from second pedal segment and extends up to fourth pedal segment. It is highly vesicular and each vesicle has its own duct. All the ducts unite to form a common duct which opens through the ventral side of the first leg bearing segment.

(2) Coxopleural glands. Last pedal segment bears numerous flask-shaped coxopleural glands. Each gland has a separate duct which opens to the exterior on the coxopleural plates.

Locomotion

Legs in scolopendra are meant for carrying the weight of the body and at the same time to provide the necessary force to bring change of position. Powerful muscles and stiff integument render the operation of leg feasible. During locomotion when legs of one side are lifted from the ground the opposite row touches it. In the same row, a leg rests on the ground immediately when the preceding leg is lifted. This results into a harmonious operation of legs and allows the animal to move forward in zigzag fashion.

Digestive system

The digestive or alimentary system includes *alimentary canal* and *digestive glands* (Fig. 16.38). The alimentary canal is divisible into three parts—*fore gut*, *mid gut* and *hind gut*. In front of the fore gut there is another chamber called pre-oral cavity which hides the mouth. The fore and hind guts have cuticular lining but mid gut is devoid of it. The fore gut is the longest part and extends up to 13th leg-bearing segment. It opens through *mouth* which remains at the anterior end and is practically concealed by the appendages. The mouth part is formed in such a way that it is forwardly directed and the parts cover each other from behind forwards. For this reason the head of Scolopendra is called *prognathus* type. The remaining part of the fore gut consists of *pharynx*, *oesophagus*, *crop* and *proventriculus*. The *pharynx* is a broad chamber with strong muscular wall. In transverse section it appears 'H'-shaped. It leads into the *oesophagus* which is a short tube and passes to an elongated thin-walled *crop*. The canal again becomes narrow and

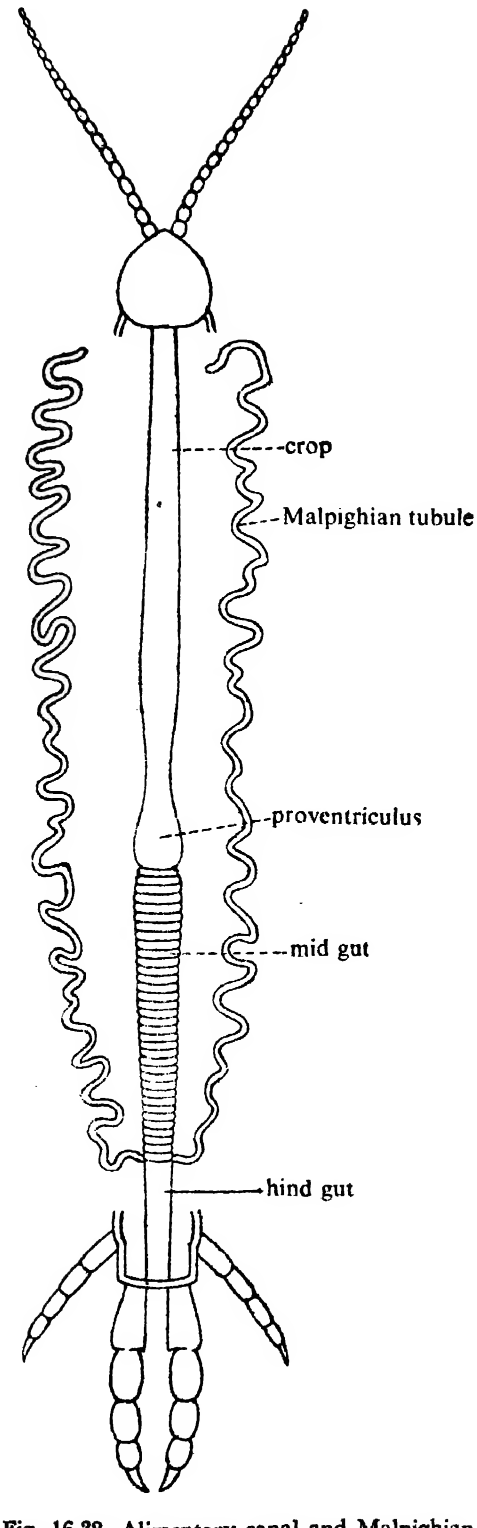


Fig. 16.38. Alimentary canal and Malpighian tubules of *Scolopendra* (Dorsal view) (after Jangi).

enters within a swollen *proventriculus*. The proventriculus opens in the mid gut which runs from 13th–19th trunk segment. The first part of the hind gut which receives mid gut is broad and a pair of long *Malpighian tubules* open near its beginning. The last part is narrow and finally communicates to the exterior through *anus*.

The glands opening in the head, i.e. epipharyngeal, labial and maxillary are the principal digestive glands of Scolopendra. They are collectively called salivary glands. The lining of the mid gut contains special types of epithelial cells which also liberate digestive enzymes. The Scolopendra is omnivorous. It preys on small insects, spiders and even the members of its own group. The mouth parts help in food getting. It also drinks water regularly to prevent the water loss. When hungry, the scolopendra is ferocious, but after a full meal it becomes sluggish and docile.

Respiratory system

Nine pairs of triradiate slit-like spiracles are present on the posterior and dorsolateral sides of the 3rd, 5th, 8th, 12th, 14th, 16th, 18th and 20th pedal segments. Each spiracle leads into *trachea*, which has spiral fibres. The tracheae branch extensively and anastomose within the different parts of the body. When at rest the spiracular muscles cause respiratory movements, but during locomotion this job is also carried by other body muscles.

Circulatory system

This system includes a circulating fluid, called *blood*, which flows through *blood vessels* and *blood sinuses*. The blood of Scolopendra is a light-yellowish fluid, in which are suspended a few corpuscles called *haemocytes*. The corpuscles are either oval or spherical or spindle-shaped and are phagocytic in nature. The blood of Scolopendra performs the following services—(1) transport of food matters, (2) carrying of waste materials, (3) convey of pressure from one end to the other and (4) reservoir of water.

The blood vessels include (1) *dorsal vessel* or *heart* and (2) *ventral* or *supraneural vessel*. The heart is an elongated muscular tube having no epithelial lining. It extends from 2nd to 21st leg-bearing segments and in the 21st segment it has become abruptly slender. The major portion of the

heart (3rd to 21st segments) remains within a thin *cardiac diaphragm*. The wall of the diaphragm is composed of two non-cellular membranes with pericardial tissue in between. In each segment the diaphragm is drawn into two points, with which it remains connected with the tergum of the segment. The diaphragm is provided with a special kind of fan-shaped muscle, called *allary muscles*. In each segment the heart communicates with the pericardial cavity by a pair of *ostia* and sends a pair of branches. The *ventral* or *supraneural vessel* also begins from second leg-bearing segment and extends up to the last segment. It runs immediately above the central nerve cord. The dorsal and ventral vessels at their anterior ends are connected by a ring-like *circum-stomodaeal vessel* which anteriorly sends four *cephalic vessels*—one *dorsal*, one *ventral* and two *laterals*. These vessels supply blood to the different parts of the anterior region—maxillipeds, muscles, antennae, brain and pharynx. There are numerous small sinuses which collect and drain blood within two large sinuses. One such sinus is called *dorsal sinus* and the other is known as *perivisceral sinus*. The dorsal sinus is present on the dorsal side between cardiac diaphragm and body wall. The dorsal sinus communicates with the ventral part of the body through the gaps of the diaphragm. The perivisceral sinus is a space around the gut which is enclosed within a perforated membrane.

The heart contracts (systole) and relaxes (diastole) rythmically and provides the force to drive the blood. At the time of diastole, heart receives blood from dorsal sinus through ostia. The systole appears as a wave-like contraction from the posterior to the anterior end and drives the blood to the various parts of the body through different vessels. The blood after flowing through smaller sinuses is collected within the dorsal sinus and again returns to the heart.

Excretory system

The excretory organs are known as *Malpighian tubules*. Two such tubules originate from the beginning of hind gut and run anteriorly. Each tubule is spirally coiled and placed on either side of the alimentary canal. The tubule has a lining of columnar epithelial cells and its lumen contains a fluid and floating degenerated cells. In addition to Malpighian tubules following structures are also known to work secondarily as excretory organs:

A. Lymphatic threads. Present around Malpighian tubules and are blue in colour.

B. Kowalevsky's corpuscles. Blue coloured small structure remains within fat body. It can absorb foreign particles like bacteria. It is believed that in addition to its excretory function it is also responsible for producing blood cells.

C. Fat bodies. These structures are mainly concerned with storage of reserve materials. But they are also known to have some excretory functions.

Nervous system

The nervous system consists of *central nervous system*, *peripheral nerves* and *sense organs*. The central nervous system is represented by (*a*) *cerebral ganglia*, a prominent two-lobed structure in the head, (*b*) *suboesophageal ganglion* on the ventral side of the head region, (c) *oesophageal commissures*, one from each side of the cerebral ganglion and uniting with the suboesophageal ganglion and (*d*) *ventral nerve cord* which begins from suboesophageal ganglion and runs posteriorly along the middle line. In each segment, there is a ganglion on the nerve cord. The ganglia of 1st and 2nd segments are closely set together and the genital ganglion is placed after the last segment.

The cerebral ganglion sends a visceral nerve to the alimentary canal. In addition, it innervates antennae, eyes and other associated structures in the head. The suboesophageal ganglion sends nerves to the jaws and maxillipedes. The ventral ganglia send peripheral nerves to the various structures in the corresponding segment.

The sense organs include (1) *sensory hairs* and (2) *spines*, which are scattered all over the body. In addition, there are (3) *maxillary organs* inside the base of 1st maxilla and (4) *organs of Tomosvary* in the base of antenna. The latter is believed to be auditory in function. But the most important sense organs are (5) *eyes* or *sensila optica*. These are paired and simple in construction.

Reproductive system

In both the sexes, the gonads are located on the mid-dorsal side of the posterior end (Fig. 16.39).

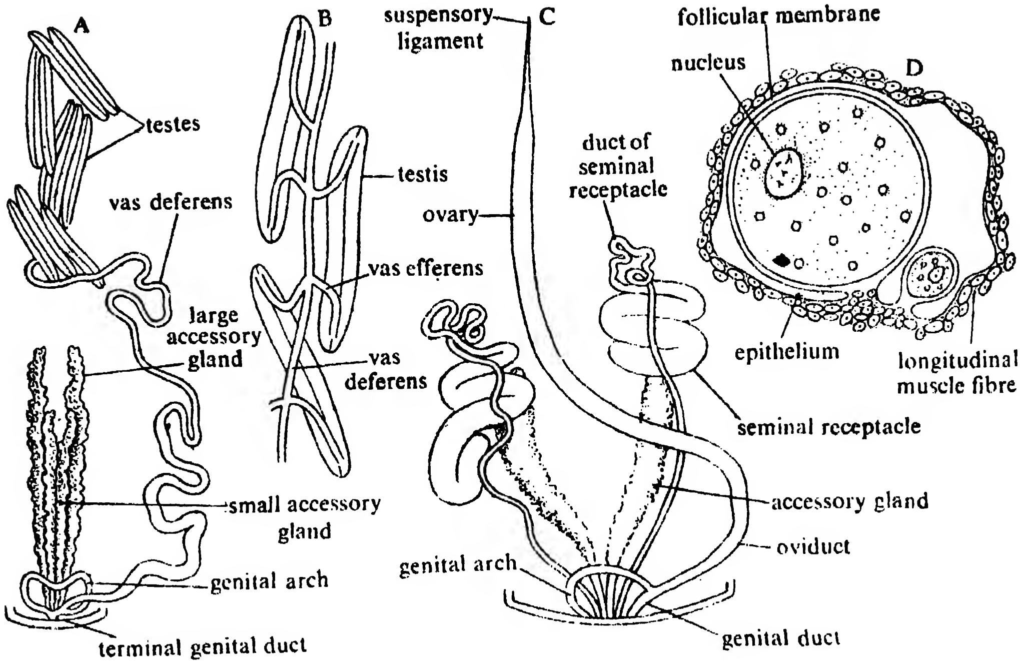


Fig. 16.39. Reproductive system of *Scolopendra*. A. Male reproductive system. B. First three pairs of testes (enlarged view). C. Female reproductive system. D. Transverse section of the ovary (after Jangi).

In males, the *testes* are twenty in number. Each testis is spindle-shaped and opens within a short *vas efferens*. All the vasa efferentia communicate with a centrally placed *vas deferens*. The vas deferens divides into two, encircles the gut and again reunites. The last part of the duct is coiled and opens to the exterior through an aperture on the ventral side and just before anus. Two pairs of accessory glands are associated with the male reproductive system. In the last pedal segment the external genitalia in male are fused with post-genital and anal parts by a membrane. The external genitalia are represented by an opening called *gonopore*, a round plate called *genital sternite* with two genital appendages. The post-genital part forms the ventral side of the copulatory organ. The copulatory organ is formed by the fusion of two sclerites and receives gonopore and the ducts of accessory glands.

In females, the ovary is a solitary tubular structure and extends along the mid-dorsal line over the alimentary canal. Like the vas deferens, the oviduct also divides and reunites. The last part of the oviduct possesses a pair of *receptacula seminalis* and two pairs of accessory glands. Female genitalia consist of two parts—genital and anal. The oviducts open within *genital atrium* which is placed inside the body and covered by *genital sternites*.

During reproduction, the males release sperm cells in packets which are called spermatophores. But the mechanism of their transfer within female is not known. The ovum is covered by a chorion and contains scattered yolk granules.

The fertilization and part of the development are internal. At a time a female Scolopendra lays 15–33 eggs and burrows them in the earth 3–8 cm deep. Each egg is nearly 3 mm in length and the entire clutch remains enveloped in a fluid medium.

Example of the Phylum Arthropoda—*MILLIPEDES*

Habit and Habitat

Altogether 92 genera and 290 species of millipedes have been recorded in India, the most well-known millipede belongs to the genus *Thyropygus*. Ten species of *Thyropygus* are known and they range from southernmost part of India to the high altitudes of the Himalayas. During rainy

season *Thyropygus* lives in moist soil and during drought it lives within burrows under the upper layers of the soil. They love to stay in calcareous soil and have special attraction for sugar and manure. The secretion of stink gland from some large millipedes may produce wound on the human skin. The species described here is known as *Thyropygus poseidon*.

External structures

An adult *Thyropygus* may be of 6 to 7 cm in length and 7–8 mm in breadth. The body is dark-brown in colour with red patches in the mid-dorsal region. The body is divisible into (1) a small *head* and (2) extended *trunk* (Fig. 16.40).

1. Head. The head is curved antero-ventrally and has powerful exoskeletal thickenings on its anterior, dorsal and lateral walls. The tergite of the first segment is called *collum* which fully covers the head anteriorly, dorsally and laterally to form a *head capsule* (Fig. 16.40). Posteriorly the head capsule remains in contact with the tergite of second segment and ventrally with a plate-like *gnathochillarium* (Fig. 16.41B). The head capsule is constituted anteriorly by a median *frons*, a pair of *clypeo-lateral lobes*. Each lobe is formed of a *clypeus* and *labrum*. The labrum is broad, freely movable and united with the ventral side of the clypeus. On the ventral side labrum constitutes a sinus. The clypeolabral lobe extends to form a concave epipharyngeal surface in the preoral cavity and sets freely on the anterior margin of the mandibles. The ventral gnathochillarium is made up of fused maxillae and is

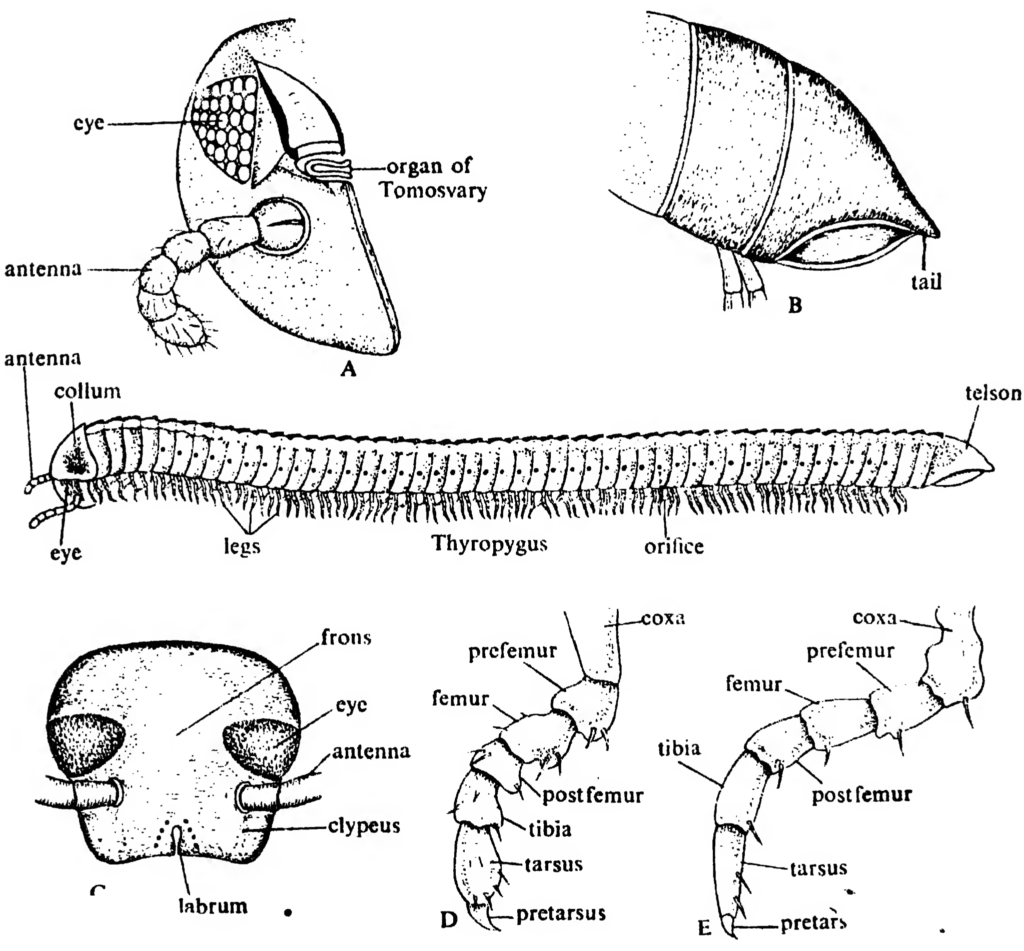


Fig. 16.40. External features of the millipede, *Thyropygus*. A. Lateral side of the head (magnified) B. Lateral side of the posterior end (magnified). C. Frontal view of the head (magnified). D. Leg from one of the anterior five segments. E. Leg from one of the last five segments (after Krishnan).

divisible into following parts: (1) *Prementum*—median, triangular plate, (2) *Mentum* and (3) *Submentum*—slender and elongated plates present posterior to prementum, (4) *Stipes*—one pair, one on each lateral and anterior side of prementum. Each stipe bears posteriorly a small *cardo* and anteriorly a pair of palps called *malagnathochillaria* carrying sensory organs called *basiconic sensillae*, (5) *Lingua*—Present in between the apex of prementum and stipes. On each side another triangular plate called *lingua* is present with lingual lobe.

Head bears following structures:

A. Eye. Paired eyes occur one on each side of the frons. The middle of each eye is raised to a point. Each eye is an aggregation of simple eyes and is provided with skeletal *ocular ridges*.

B. Organ of Tomosvary. Paired sensory organs, present one on each side and slightly ventral to the eye.

C. Antenna. Paired antennae, originate one from each anterior side of the head. Each antenna is seven-segmented and placed within membranous antennal socket.

2. Trunk. The trunk contains nearly 47–48 segments. All the segments are doubled and such possession of diplosegments is regarded as the characteristic feature of millipedes. Each segment has both exoskeletal and endoskeletal coverings. The cuticle in each segment is completely ring-like. The segments are attached with one another by a thin membrane. The terminal segment or anal segment or *telson* is more or less triangular and bears a short upwardly directed curved tail. The trunk region contains following structures:

a. Legs. The first five segments superficially appear to be single and carry only one pair of legs in each segment, while remaining segments have two pairs of legs in each of them. Each leg has following parts—coxa, prefemur, femur, postfemur, tibia, tarsus, pretarsus and a terminal claw (Fig. 16.40D, E). In males, the legs of the seventh trunk segment are modified as intromittent organs and known as *gonopods* (Fig. 16.41C).

b. Stink gland. The paired openings of the stink gland are present on the dorsolateral side of each trunk segment, excepting first five and last few segments. Inside the body cavity, each stink gland is globular and sac-shaped. It has a long neck called ejaculatory duct which possesses a cuticular tongue near its opening.

The ejaculatory duct and the tongue are provided with muscles and nerves. The secretion generally oozes out through the opening but may also be darted as a jet.

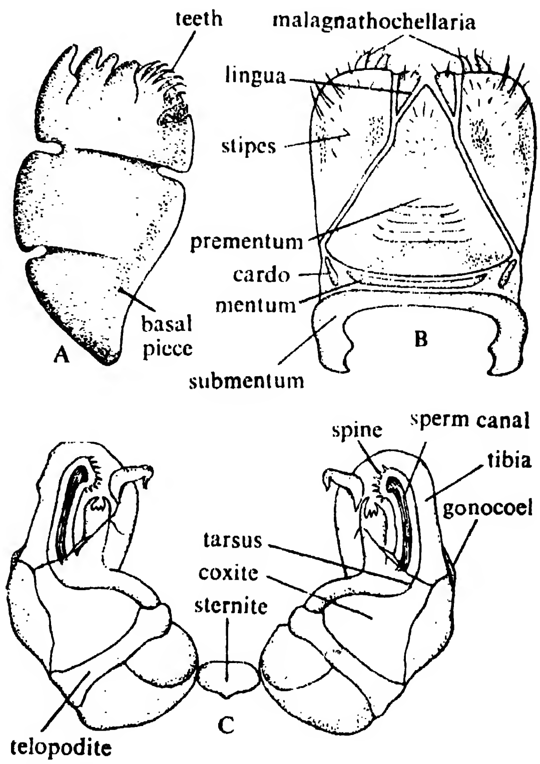


Fig. 16.41. Mandible (A), Gnathochillarium (B) and Gonopods (C) of *Thyropygus* (after Krishnan).

c. Stigmata. These minute opening are present ventro-laterally on each segment. The first three segments bear one pair of stigmata while the remaining segments have two pairs in each of them. These openings communicate with the inner tracheal pockets or pouches.

d. Anus. It is the posteriormost terminal opening of the alimentary canal and present in the last segment and directed ventrally. Various structures which are present inside the trunk segments are shown in the figure.

Integumentary system

The integument is represented by an outer cuticle and inner epidermis (Fig. 16.42). During summer cuticle may be distinctly separated into *epicuticle* and *pro-*

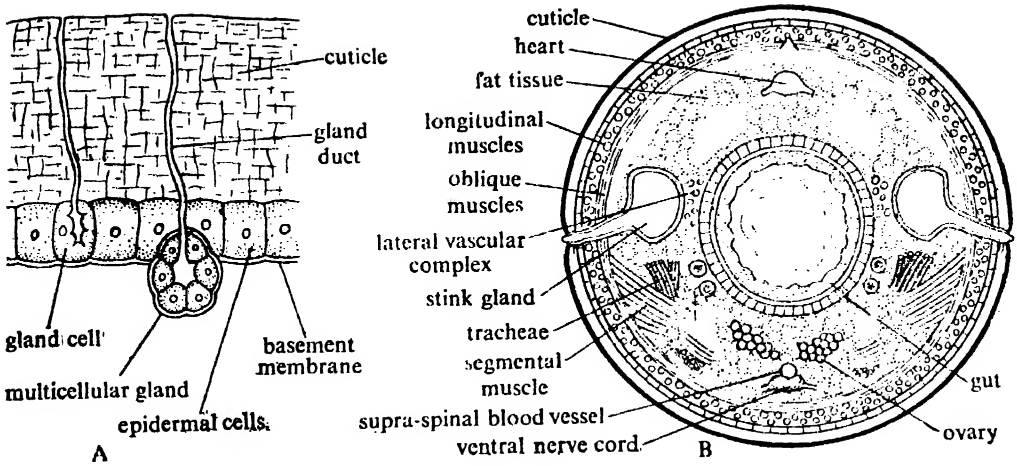


Fig. 16.42. A. Transverse section of the integument of *Thyropygus*. B. Transverse section of *Thyropygus* through the mid-gut region (after Krishnan).

cuticle, but in rainy season epicuticle disappears. The procuticle is again divided into a thin homogeneous outer *exocuticle* and thick, lamellated inner *endocuticle*. The epidermis includes one layer of large cells on a sheath of basement membrane. The epidermal cells perform three important functions—(1) secrete a juice which digests the old cuticle, (2) produce the cuticle and (3) release certain substances which stiffen the cuticle. Number of unicellular and multicellular glands are present in the epidermis. Each gland has a duct of its own, which traverses through the cuticle and opens to the exterior through minute apertures.

Digestive system

The alimentary system includes (A) *Alimentary canal* and (B) *Digestive glands* (Fig. 16.43).

A. ALIMENTARY CANAL. It is more or less a straight tube which is divisible into three parts: (1) *Fore gut*, (2) *Mid gut* and (3) *Hind gut*. The fore and hind guts have inner cuticular lining.

1. *Fore gut*. It includes (*a*) *mouth*, (*b*) *mouth cavity* and (*c*) *oesophagus*.

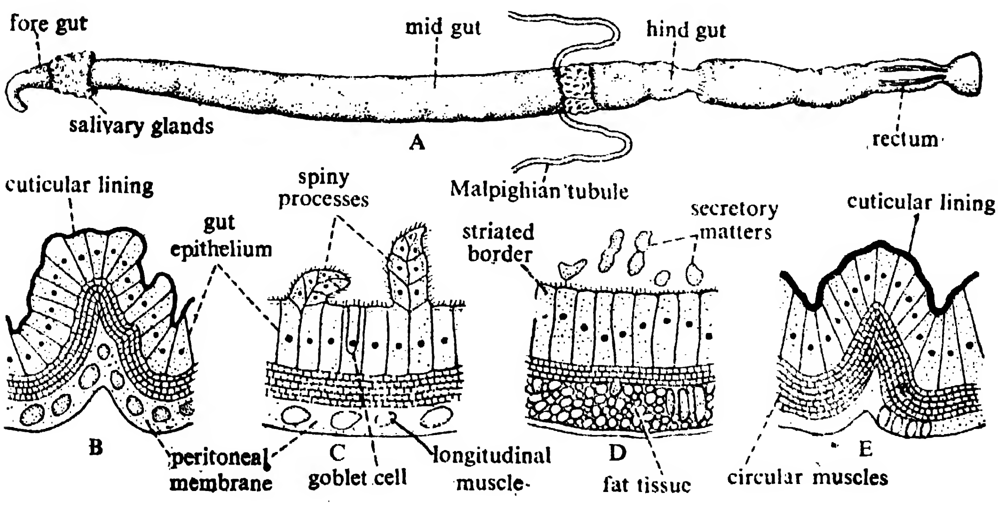


Fig. 16.43. A. Alimentary system and associated structures of *Thyropygus* (only the proximal part of the Malpighian tubule is shown). B. T.S. of the wall of oesophagus. C. T.S. of the wall of the fore gut (posterior end). D. T.S. of the wall of the mid gut. E. T.S. of the wall of the hind gut (after Krishnan).

(*a*) MOUTH. This crescent-shaped opening is present at the ventral side of the head region and betweenepicranium and gnathochillarium. It leads into mouth or oral cavity.

(*b*) MOUTH CAVITY. The anterior end of the cavity is formed by the inner side of the epicranium and the posterior side by gnathochillarium. Mandibles with teeth and bristles bound its lateral sides (Fig. 16.41A). The cavity is divided into two chambers by the projection of the hypopharynx. The mouth cavity opens within the next part of the canal called oesophagus.

(*c*) OESOPHAGUS. This short tube, immediately after originating from the mouth cavity runs dorsally, then takes a turn to the posterior direction and passes ventral to the brain. It continues up to seventh or eighth segment. The inner wall of the oesophagus is folded to form villus-like structure like the small intestine of higher animals. These projections are more extensive in the anterior part. The inner cuticular lining is also much thicker at the anterior part but at the posterior region numerous spiny processes are present. Beneath the inner cuticular lining lies a layer of columnar epithelial cells. This is covered by distinct layers of circular and longitudinal muscles, which in turn are enclosed within a peritoneal membrane. The longitudinal muscles are broad and placed apart from one another. This gives the characteristic appearance of the fore gut.

2. *Mid gut*. It runs up to thirty to thirty-two segments. The terminal part of the mid gut is marked by a swelling of fatty tissue, from where originates the paired Malpighian tubules. Following are the characteristics of the mid gut region:

(*a*) It is wider but thin-walled.

(*b*) Longitudinal muscular bands are narrow.

(*c*) Circular muscle layer is thinner.

(*d*) Presence of a fatty tissue beneath the peritoneal lining.

(*e*) Inner cuticular lining is absent.

(*f*) Epithelial cells are of various shapes and have an inner striated border.

(*g*) Epithelial cells are secretory and absorptive in function.

3. *Hind gut*. This is the last part of the alimentary canal which terminates in an aperture called anus. The first part of the hind gut is of same thickness as the mid gut, but after a couple of segments, it becomes wider. The beginning of this wider region is marked by a constriction. The posterior part is again narrow and has thick muscles in the wall. The hind gut has the following features:

(*a*) Circular muscles are well-developed specially at the posterior part.

(*b*) The wall of the hind gut is internally projected into folds.

(*c*) Epithelial cells are cubical and have no striated border.

(*d*) Inner cuticular lining is of much lesser thickness than the fore gut.

DIGESTIVE GLANDS. Most important gland for digestion is the salivary gland (Fig. 16.44). One pair of lobular glands

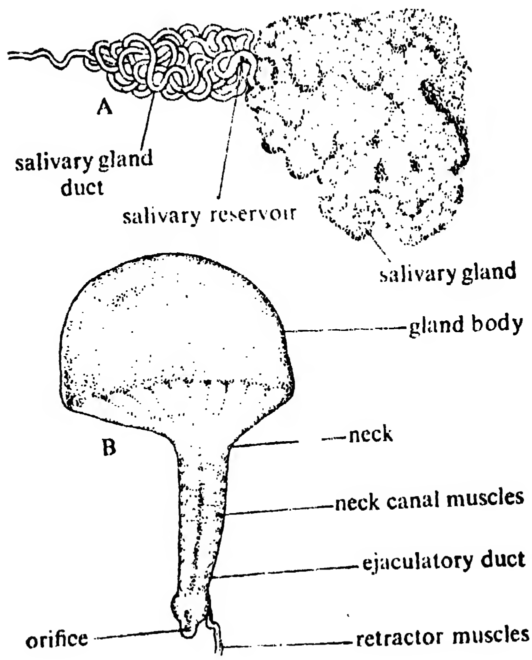


Fig. 16.44. A. Salivary gland with duct of *Thyropygus*. B. Stink or Repugnatorial gland of *Thyropygus* (after Krishnan).

are present in the dorsal side of the oesophageal region. From each salivary gland, minute tubules drain into a salivary duct. The first part of the duct is sac-like and acts as *reservoir*. It continues as slender much coiled duct which runs anteriorly to open within the mouth cavity near the inner side of gnathochillarium. The details about the nature of enzymes in the saliva

are not known but the products are obviously digestive in function.

In addition to salivary gland, the lining of mid gut contains secretory cells which also produce digestive juices.

Mechanism of feeding and digestion. The food includes soft parts of plants or decaying animals. It likes calcium containing leaves and prefers glucose and sucrose more than starch. The mid gut is the region where digestion and absorption take place. The lining of the hind gut absorbs water from the residual food.

Circulatory system

The circulatory system includes (*a*) *heart*, (*b*) *blood vessels* and (*c*) *blood*.

A. Heart. The heart is an elongated tubular organ which begins from the first segment and continues up to anal segment. It is present along the mid-dorsal line of the body cavity and is placed above the alimentary canal. It is enclosed within a pericardial membrane. Heart is constricted into a number of chambers, each segment having one. In between the two chambers there is a pair of lateral openings called *ostia* through which blood enters within the heart. The wall of the heart is provided with muscles for both contraction and relaxation.

B. Blood vessels. In each segment heart sends a pair of *lateral arteries* each of which bifurcates and each branch passes around the gut to open within a median ventral artery called *supraspinal blood vessel*. Before opening into the latter, the lateral artery sends a complex of lateral vessels to supply blood to the different parts of the segments. Anteriorly the first chamber of the heart continues as a *median cephalic artery*. The cephalic artery sends two pairs of lateral vessels which after sending branches to the parts around the mouth cavity finally open within the supraspinal vessel. The cephalic artery finally breaks into a number of branches to supply brain and other structures in the head region. The *ventral supraspinal vessel* also sends number of segmental branches to vascularise the different parts of the body. The blood flows anteriorly through the heart and posteriorly through supraspinal vessel. Blood from arteries finally enters within the haemocoelomic space and bathes the tissues. From these tissue spaces blood returns through *lacunae* and enters within the heart through ostia.

C. Blood. Blood contains a liquid part *plasma* and three types of floating corpuscles or *haemocytes*. Various substances like protein, fat, sugars, free amino-acids, etc., are found in the plasma. Most common types of haemocytes are small in size but they possess large nuclei. The other type of haemocyte is large, oval, with distinct nucleus and granulated cytoplasm. The third category of haemocytes is spindle-shaped. Blood in millipedes is not involved in transport of respiratory gases. It is concerned with food storage, wound repair, defence against foreign bodies and excretion.

Respiratory system

Respiratory organs are in the form of *tracheae* (Fig. 16.45). In *Thyropygus*, the

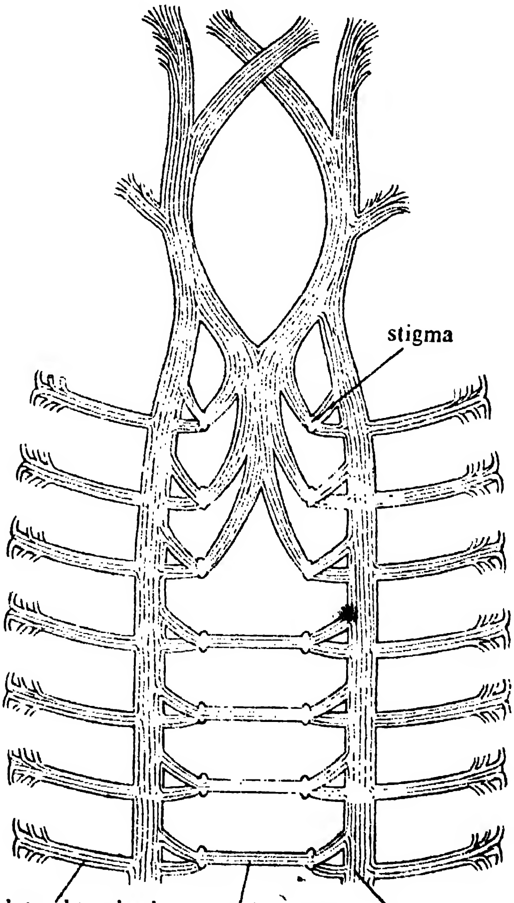


Fig. 16.45. Arrangement of tracheae at the anterior end of *Thyropygus* (after Krishnan).

tracheae are unbranched. A major tracheal trunk includes a large number of smaller tracheal tubes and each trachea is made up of several tracheoles. The trachea has cuticular lining but the spiral thickening is not distinctly visible. The tracheae communicate with the exterior through minute valve-fitted apertures called stigmata. Each segment bears two pairs of stigmata, excepting the first three which possess one pair per segment. Each stigmata leads into a *tracheal pouch* formed by epidermal invagination. From each tracheal pouch, three sets of tubes originate, (*a*) transverse bundle directed ventrally between the opposite pouches, (*b*) one lateral tube on each side running dorsolaterally to supply finer tubes to the different parts of the corresponding segment, (*c*) a pack of tubes which join with a common *ventral tracheal trunk*. The two ventral tracheal trunks run along the entire length of the body and break up into finer vessels to supply the head region. Finer tracheolar tubules are immersed in haemolymph and open directly within the tissue. Same set of vessels convey both oxygen and carbon dioxide.

Excretory system

The cuticle and Malpighian tubules (Fig. 16.46) are regarded as the organs for removing metabolic wastes. The waste products like uric acid are deposited in the cuticle and are shed at the time of moulting. Malpighian tubules are two in number, originating from the ventro-lateral side of the mid gut near its junction with hind gut. The region of origin is surrounded by a ring of fat tissue. Each tubule, immediately after its origin, is directed posteriorly and then it takes a turn to run anteriorly up to the oesophagus. From there the tubule bends posteriorly and comes up to the rectum. It then again turns upward and ends blindly. The tubule is convoluted and capable of various movements. It remains immersed within haemolymph from where it collects excretory products in the form of uric acid and ammonia. The waste products are deposited inside the alimentary canal and are ejected with the faeces. The transverse section of the tubule shows following structures from outside to inside—(*i*) outer *peritoneal layer* with numerous externally placed tracheal tubule, (*ii*) *muscular layer* with striated fibres, (*iii*) a *layer* of large *cubical cells* having striations at the inner border.

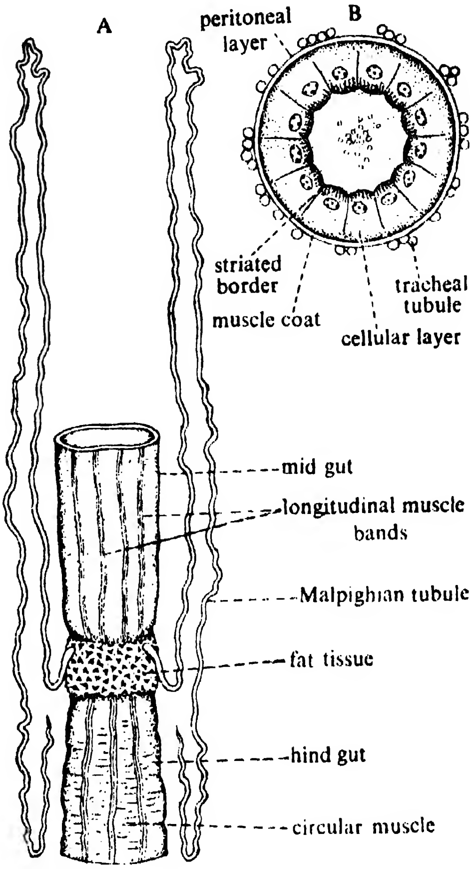


Fig. 16.46. A. Malpighian tubules of *Thyropygus*. B. Transverse section of a Malpighian tubule (after Krishnan).

Nervous system

The nervous system includes (*a*) *Central nervous system*, (*b*) *Peripheral nervous system*, (*c*) *Sympathetic nervous system* and (*d*) *Sense organs*.

A. Central nervous system. It consists of (1) a large *supra-oesophageal ganglion* or *brain*, (2) paired *circum oesophageal commissures*, (3) paired *sub-oesophageal ganglion* and (4) elongated *ventral nerve cord* (Fig. 16.47).

1. Supra-oesophageal ganglion. Though it appears to be a single large ganglion, yet it is formed by the fusion of several ganglia. It may be distinctly divided into three regions, *protocerebrum*, *deutocerebrum* and *tritocerebrum*. The protocere-

brum contains two *frontal* and two *lateral lobes*. The deutocerebrum has a pair of *antennal lobes*, and tritocerebrum includes two *lateral lobes*.

2. CIRCUM-OESOPHAGEAL COMMISSURES. From each lateral side of the supra-oesophageal ganglion a stout oesophageal commissure runs ventrally to unite with the sub-oesophageal ganglion.

3. SUB-OESOPHAGEAL GANGLION. Paired sub-oesophageal ganglia appear to be single and the ganglionic swelling is not very prominent. It is connected posteriorly to the ventral nerve cord.

pairs of nerves. In each side one nerve goes to the corresponding leg and other nerve sends branches to the muscles, trachea, stigmata and wall of the heart in the same segment.

C. SYMPATHETIC NERVOUS SYSTEM. It is represented by one unpaired and one paired nerve cords. All of them originate from the brain and run posteriorly. In the paired nerves swollen ganglia are formed.

D. SENSE ORGAN. Following sense organs are seen in *Thyropygus*—(1) *Antennal sense organs*, (2) *Gnathochillarium*, (3) *Organs of Tomosvary*, (4) *Hydroreceptor organs* and (5) *Eyes*.

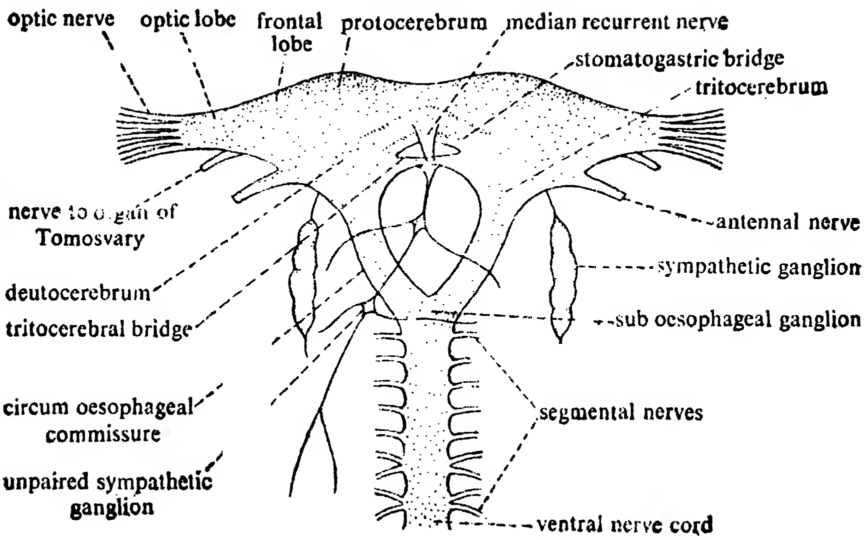


Fig. 16.47. Nervous system of *Thyropygus*—anterior part.

4. VENTRAL NERVE CORD. The dorso-ventrally flattened ventral nerve cord is formed by two separate cords which are completely fused to be one. It runs posteriorly along the mid-ventral line. In each segment it sends two pairs of peripheral nerves but does not possess segmental ganglion.

B. PERIPHERAL NERVOUS SYSTEM. Number of peripheral nerves are given off from the central nervous system to the different parts of the body. The optic nerves and nerves to the organ of Tomosvary arise from the lateral lobes of the protocerebrum. The nerves to the antenna originate from antennal lobes of deutocerebrum. The brain also sends nerves to the gnathochillarium and mandibles. In each segment ventral nerve cord sends two

1. *Antennal sense organs*. Short, seven-segmented antennae bear three types of sense organs (Fig. 16.48A, B): (*a*) sensory bristles, (*b*) cone sensillae and (*c*) peg organs.

(*a*) SENSORY BRISTLES. These bristles are scattered all over the antenna and contain sensory cells at their bases.

(*b*) CONE SENSILLA. The two terminal segments of each antenna are transformed into conical structures containing sensory cells. These are called cone sensillae and they act both as chemoreceptor and taste organs.

(*c*) PEG ORGAN. The last segment bears hook-like structures called peg organs.

They also work as chemoreceptor and taste organ.

2. *Gnathochillarium.* Numerous sensory structures called *basiconic sensillae* are present over the distal end of the *gnathochillarium.* These are also gustatory in function. They may also show taste discrimination.

3. *Organs of Tomosváry.* Each of these appears as a cuticular depression with the lining of sensory cells which receive nerve supply from the optic nerve (Fig. 16.48C). This organ is believed to be responsible for determining vibration and also to react properly to the gravity.

5. *Eyes.* Each eye is made up of several simple eyes or ocelli. Each ocellus is formed by the modification of integument and in section it looks like a glass. The sides and the floor are made up of single-layer sensory epithelial cells. The cells lining the floor become pigmented and form retinal layer and the cuticles above are modified as lens and cornea.

Reproductive system

The sexes are separate and the sexual differences are noted from the structure of legs in the seventh segment of male where these legs are modified into intromittent organs or gonopods.

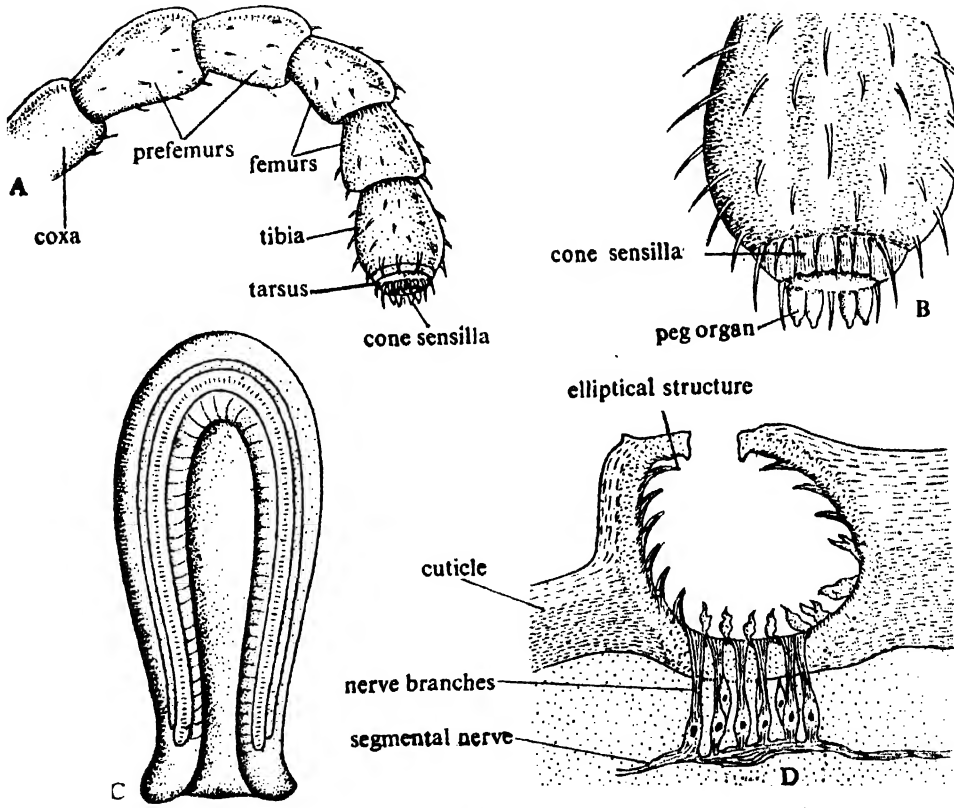


Fig. 16.48. A. Antenna of *Thyropygus*. B. Distal segment of the same antenna. C. Organs of Tomosvary and D. Hydroreceptor organ of *Thyropygus*. The hydroreceptor organ is shown in sectional view (after Krishnan).

4. *Hydroreceptor organ.* These paired organs (Fig. 16.48D) are present one on each side near the base of gnathochillarium. It is responsible for determining the water or moisture content of the soil. Structurally it resembles the tarsal organ of the spider but functionally these two are completely different.

Male reproductive system includes *testes, sperm ducts, penis* and *gonopods*. Each testis is tubular and extends from second to fortieth segment of the body. It is placed between the alimentary canal and ventral nerve cord. The posteriormost part of the testis is tube-like, the middle part is beaded and the anterior end is convoluted. At the

anteriormost part the two testes are transversely joined by small tubes. Sperm duct originates from each testis at the third segment and runs up to the second segment and finally communicates ventrally with a small penis. The gonopods collect the sperms from the sperm duct and at the time of copulation sperms are transferred to the female genital tract.

The female reproductive system consists of an *ovary*, a short *uterus* and paired *vulvae*. The ovary is placed mid-ventrally above the nerve cord and is conspicuous only during maturity. It contains ovisacs, each of which holds a single egg. The ovary continues as uterus which in the third segment bifurcates into two smaller tubes. Each small tube opens externally through a vulva which is placed laterally.

Fertilization and Oviposition

During copulation sperms are transferred by the gonopods of the male within the vulvae of the female. The sperms remain viable for a considerable period in the vulvae and fertilization takes place at the uterus after certain period of copulation. Eggs are laid in successive batches. Each egg is laid with a spherular wall formed by the secretion of the female. Eggs are generally laid at night within the chambers of burrows specially prepared for the purpose.

Example of the Phylum Arthropoda—*COCKROACH*

The cockroaches belong to the class Insecta or Hexapoda and under the order Dictyoptera. The word cockroach has probably originated from the name of a Spanish fruit, "cucaracha", having disagreeable taste. There are several types of cockroaches. The one which is described here is known as *Periplaneta americana*. The word *Periplaneta* (*Peri*=about; *planeta*= wandering star or planet) indicates the world wide distribution of this insect. This was possible through its travelling by ships. The other cockroaches (Fig. 16.49)

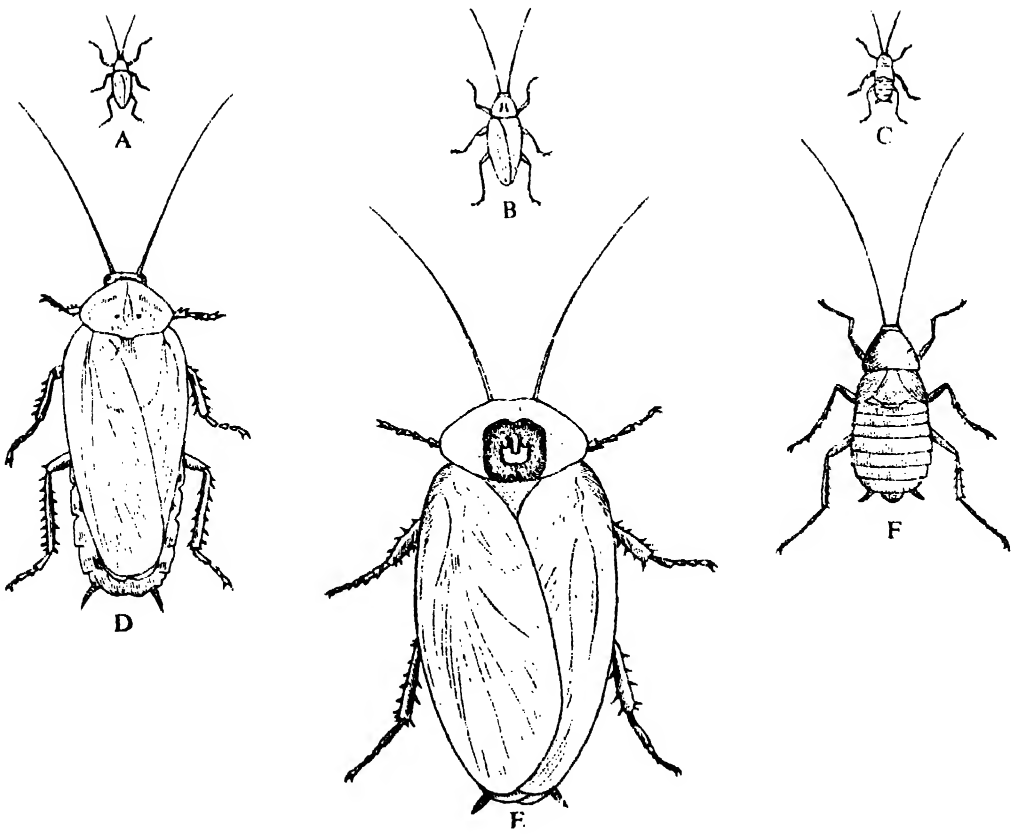


Fig. 16.49. A few types of cockroaches—A. *Ectobius pallidus*. B. *Blatella germanica*. C. *Ectobius panzeri*. D. *Leucophaea maderae*. E. *Blaberus cranifer*. F. *Blatta orientalis* (after Guthrie and Tindall).

are *Blatella germanica*, *Leucophaea maderae*, *Blaberus craniifer*, *Ectobius pallidus* and *Ectobius panzeri*. Different species of cockroaches differ in size and other characteristics but all of them exhibit certain common features. Well-developed wings are present in both sexes. In males, the wings extend beyond the abdomen. In females, keel-like ovipositor valves are present.

Habit and Habitat

The cockroach, *Periplaneta americana*, is a common nocturnal omnivorous household pest which also acts as a scavenger. It prefers dark warm corners of kitchens, godowns, underground drains and places where food and humid atmosphere are available. The cockroaches are now distributed throughout the world. The cockroaches probably originated in Southern Asia or Africa and became the dominant fossils of the Carboniferous age (some aurhors have called it as "The age of cockroaches"). Cannibalism is often seen amongst cockroaches. The ability to walk rapidly and the production of a pungent secretion from the abdominal glands are regarded as the defensive mechanisms of this insect.

External structures. The body is dorso-ventrally flattened, elongated and reddish-brown in colour. The cockroach can easily creep inside the small cracks and crevices. The males are usually 35–40 mm in length and females are 29–37 mm. The body is segmented (Fig. 16.50) and the segments are organised to form three distinct specialised parts, each of which is called a *tagma*. The three tagmata are—*Head*, *Thorax* and *Abdomen*. All the three tagmata are enclosed by exoskeletal coverings. Several structures occur in each tagma.

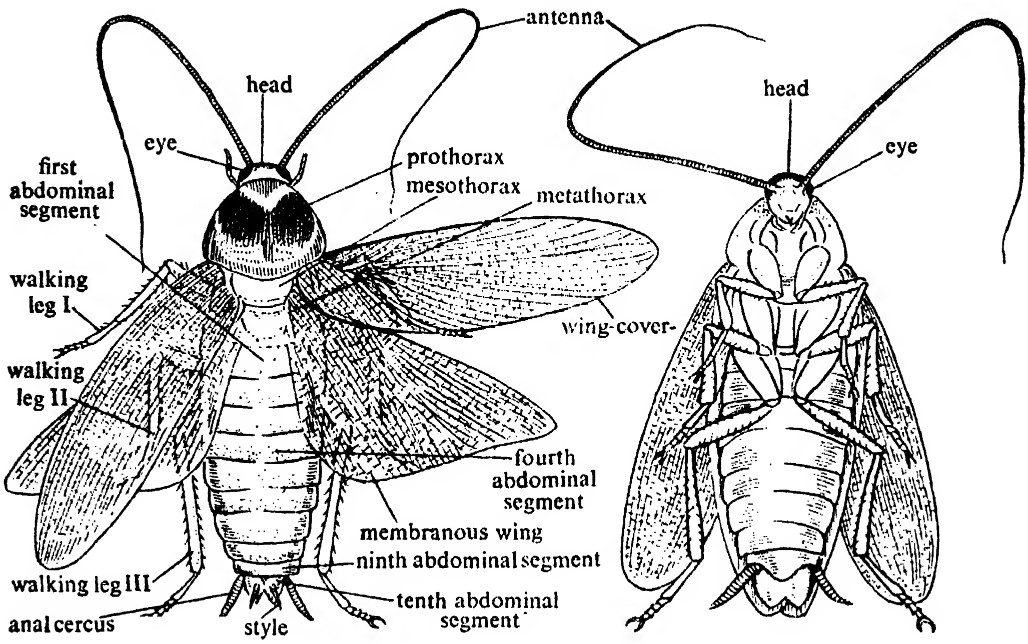


Fig. 16.50. External features of *Periplaneta americana*. A. Dorsal view. The wings are extended to show all the segments. B. Ventral view.

HEAD. It is the anteriormost part of the body and is more or less triangular in shape. It is formed by the fusion of six segments which have lost their external demarcations. The exoskeletal covering of the head is called the *head capsule*. It includes (1) a pair of *epicranial plates* or *occipital sclerites*, covering dorsal and posterior parts; (2) a single piece formed by the fusion of two exoskeletons, *frons*, *clypeus* and *labrum*, hangs in front of head and (3) two exoskeletal pieces, the *genae*, cover each side of the head. On each side, the gena is separated from the frons by a *fronto-genal suture* and the labrum is attach-

ed with the distal border of the clypeus. Following structures are present on the head region: (*a*) EYE. One pair of prominent sessile eyes is present, one on each side of the head and the two eyes occupy much of the antero-lateral wall. Each eye is bean-shaped and compound in nature. The external surface is marked with several polygonal facets, each of which denotes a single visual unit—*ommatidium.* The eyes are larger is males than in females. (*b*) ANTENNA. A pair of thread-like elongated antennae is present in the antero-medial indentation of the eyes. Each antenna articulates on a ring-like sclerite at two points—one, which is rigid is known as *antennifer* and the other is flexible, called *surantennifer.* The antennae can be moved freely in all directions. (*c*) OCELLUS. The ocelli are paired circular areas one on each side of the eye, near the base of the antennae. Each area acts as a simple eye and is responsible for detecting light. (*d*) MOUTH. It is placed at the anterior end of the head. It is provided with several appendages and other associated structures, which are collectively known as *mouth parts* or *trophi.*

MOUTH PARTS OR TROPHI. The mouth parts (Fig. 16.51) are composed of paired appendages like *mandibles, maxillae* and the *labium.* The other structures which participate in the formation of mouth parts are the *hypopharynx* and *labrum.* Each part of the trophi is discussed below:

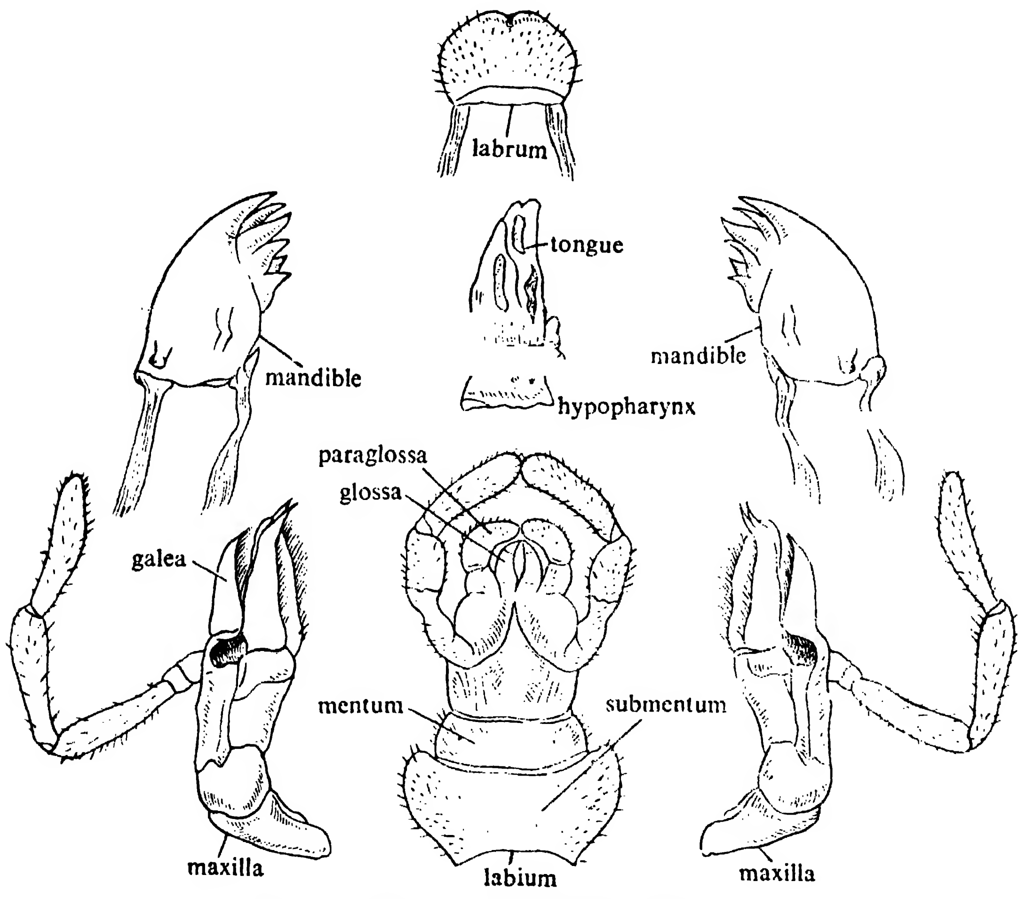


Fig. 16.51. Mouth parts of *Periplaneta americana.*

Mandibles. These paired appendages are present one on each side of the mouth. There is a soft cuticular area in the base of the mandible called the *submolar region.* The remaining part of the mandible is hard. Each mandible bears two surfaces, one on each outer basal angle. These are called *condyles.* One condyle articulates with the clypeus of the head and the other one articulates with the gena. The inner border of the mandible is sharply serrated.

The teeth of the left mandible lie dorsal to the teeth of the right mandible and both the mandibles work like a saw to cut the food into pieces.

Maxillae. These paired appendages are present one on each side of the mandible. Each maxilla is a many-jointed structure and contains following pieces from proximal to distal end—*cardo*, *stipes*, *lacinia* and *galea*. When the mouth parts are not working the two galea completely enclose the laciniae. The basal tip of cardo bears a condyle for articulating with the exoskeleton of the head. An inner groove separates the cardo from stripes. A membrane from the middle of the stipes extends up to the head. From the distal end of each stipe arise a many-jointed lateral *maxillary palp*. This appendage is used for holding the food and thus assists during ingestion.

Labium. This median single structure is, in fact, formed by the fusion of two appendages. It is divisible into a proximal part called *submentum* and a distal part, *mentum*. The submentum articulates with the head immediately near the articulation of maxillae. The free end of mentum carries following paired parts from outer to inner side—many-jointed *labial palps*, short *paraglossae*, and small *glossae* with curved claw at the tip.

Hypopharynx. This fleshy central part is bounded dorsally by mandibles, ventrally by the labium and laterally by maxillae. A membrane from the inner border of the labium is continuous with its ventral side. The salivary duct opens in the middle of the ventral side and near the base. The hypopharynx is also termed as *tongue* or *lingua*.

Labrum. It articulates with the distal end of clypeus in the head region. Its dorsal side is hard but ventral side is soft and is known as the *epipharynx*.

THORAX. The head is connected with the next tagma, the thorax, by a short *neck* or *cervicum*. A large membrane connects the head with the thorax. The thorax is divisible into three segments—*prothorax*, *mesothorax* and *metathorax*. The neck is the forward extension of the prothorax. A large sclerite covers the prothorax dorsally. It extends anteriorly to cover the head and posteriorly to shield the mesothorax. This sclerite also extends laterally. The central part of this sclerite is lighter in colour than its periphery. A slender line runs along the middle and bifurcates posteriorly. The mesothorax is covered by a round sclerite having a central triangular marking called the *scutellum*. A transverse line above the pointed apex of the scutellum divides the sclerite into an anterior and a posterior part. The anterior part is called *prescutum* or *preallar* sclerite, which looks like an independent sclerite but actually it is a part of the mesothoracic sclerite. Posterior to the prescutum lies the *scutum* which on each side bears one anterior and one posterior tergal process for the articulation of the fore wing. The exoskeleton of metathorax resembles that of the mesothorax. But here the prescutum is not so well-marked. The anterior and posterior tergal processes are present on the lateral side of the scutum for the articulation of the hind wings. Each thoracic segment carries a pair of walking legs. All the legs are of similar shape and structure. The first leg is the smallest and the third leg is the largest. Each thoracic leg (Fig. 16.52) consists of following parts:

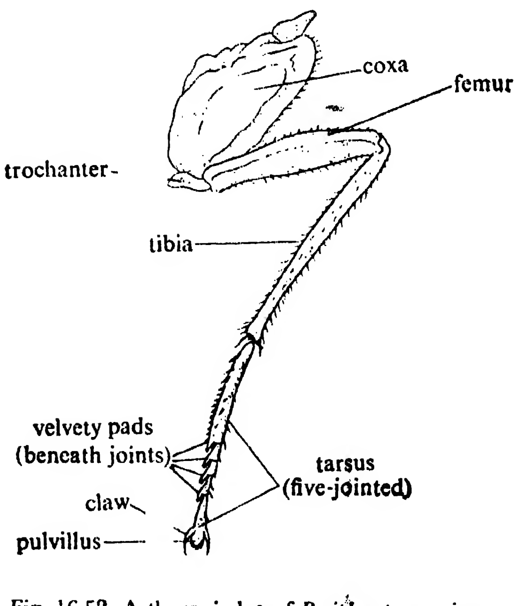


Fig. 16.52. A thoracic leg of *Periplaneta americana*.

(1) *Coxa*. Proximal part of the leg which is broad and flat.

(2) *Trochanter*. Small part which serves as a joint between the coxa and the next part, femur.

(3) *Femur*. Long and flat portion with outer spiny border.

(4) ***Tibia.*** Narrow and long portions with numerous spiny projections called ***tibial spurs***.

(5) *Tarsus*. This is the distal part of the leg. It is five-jointed and each part is called a ***podomere***. Beneath the joints there are soft pads called ***plantulae***. The terminal podomere is known as ***pretarsus***, which bears two claws and a thin hairy pad called ***arolium*** or ***pulvillus***. The mesothorax and metathorax of an adult cockroach carry a pair of ***wings*** on the dorsal side of each segment. During rest the dark coloured leathery mesothoracic wings called ***wing cover*** or ***tegmina*** or ***elytra***, cover the thin and membraneous metathoracic wings which are used for flight. The wings are exoskeletal modifications. Each wing is composed of double layers of chitin with branched tracheoles in between.

Abdomen. The abdomen is the longest tagma of the body, which is divisible into ten segments. The entire abdomen is dorsoventrally flattened. Last few segments are short and closely set. The last part of the abdomen in both the sexes is modified to take part in the formation of an area where reproductive ducts open and the area is provided with certain genital appendages (Fig. 16.53).

A female cockroach bears following structures in the last part of the abdomen: (1) *Hypogynum*. It is formed by the close apposition of the sternites of both the sides of seventh abdominal segment towards the posterior direction. In between these two sternites, a fleshy lobe is placed with one small anterior and a large posterior folds. Dorsally the two folds bear a structure called ***paraprocts***, within which opens the anus. (2) *Epiprocts*. The tergite belonging to the tenth abdominal segment extends posteriorly as incompletely bifurcated flexible projection, carrying three *gonapophyses* or ***ovipositors*** having sclerites called *valvifers*. (3) *Cerci*. These paired structures are borne by the lateral side of the paraproct and articulate distally with the anterior end of the epiproct and the tergites of the tenth abdominal segment.

In addition to the above mentioned structures, the eighth abdominal segment bears three sclerites—two *laterals* (also called ***basisternite***) and a single ***median***. The spermathecal apertures open within the posterior projection of median sclerite and vulva or female gonopore is present on the ventral side of the two basisternites.

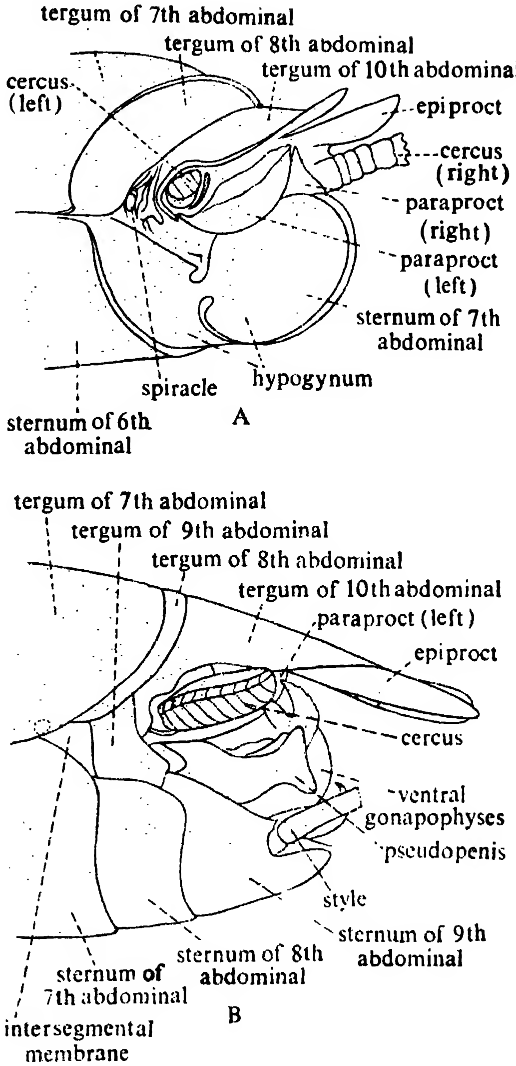


Fig. 16.53. Structures present in the posterior end of the abdomen of *Periplaneta americana* (Lateral view). A In female. B. In male (after Guthrie and Tindall).

The posterior end of the abdomen in a male cockroach also exhibits specialisation. Here the sternum of the ninth abdominal segment is drawn anteriorly up to seventh abdominal segment and it bears following structures—*cerci*, ***epiprocts***, *styles* and ***gonapophyses***. The first two structures correspond to the identical structures of females. A pair of rudimentary undivided *stylets* is present on the ninth segment. Three *gonapophyses*, two lateral and one ventral are placed within a chamber formed dorsally

by paraprocts and ventrally by the sternum of ninth abdominal segment. In between lobes of the gonapophyses opens the duct from *conglobate gland* and the left gonapophysis bears a slender *pseudopenis*.

Integumentary system

The details about the integumentary system are discussed in the latter part of this chapter under general account of arthropods. It may be mentioned here that the body of cockroach is covered by a *cuticle* which is impermeable to water. Numerous fine tubules originating from the lower epidermal cells traverse the cuticle. The cuticle is divisible into (*a*) inner thick *precuticle* and (*b*) outer thick *epicuticle*. The innermost part of the epicuticle is formed by a substance called *arthroidin* and its outer part is a thin polymer layer. This polymer layer is coated externally by a substance called *amphion*, which is formed by a combination of wax and cement. The amphion makes the cuticle impervious to water. The most important integumentary glands are *cervical glands* and *abdominal glands*. The cervical glands are present within the membranes which cover the neck and its product is called '*periplanetin*'. The abdominal glands include *dorsal abdominal gland* in between the terga of 5th and 6th abdominal segments and *ventral abdominal gland* in between the sterna of 6th and 7th abdominal segments. These abdominal glands produce a substance having pungent smell which is used for defence.

Muscular system

The muscles of cockroach may be classified into two broad groups—*skeletal muscles* and *visceral muscles*. There are nearly 370 pairs of skeletal muscles, of which 51 pairs are present in the head. The skeletal muscles supply the mouth parts, thoracic legs, wings and genital appendages. In males, the wing muscles are opaque and pink but in females these muscles are hyaline and white. When compared with the histology of muscles of vertebrates (as discussed earlier), the skeletal muscle fibrils of insect show that Z-membrane, I-band, and A-bands are prominent but M-line is absent and H-band is inconspicuous. The mitochondria are arranged on the opposite sides of the I-bands.

The visceral muscles include gut and heart muscles. The wall of the gut contains an outer coat of circular muscles and an inner coat of longitudinal muscles. In the posterior region of crop and in the mid gut the longitudinal muscles are narrow but strongly developed in the anterior region of crop, colon and rectum. The most important heart muscles are fan-shaped allary muscles. The other visceral muscle of heart is a thin circular layer around heart with distinct nuclei. The histology of heart muscles exhibits the presence of intercalated discs in between the muscle cells, a plasmalemma having intimate connection with endoplasmic reticulum and complex mitochondria between the myofilaments.

Body Cavity

The body cavity in the form of coelom is present only in the embryonic condition. In adult the body cavity is formed by the fusion of embryonic blastocoel with the embryonic coelomic space and is called *mixocoel*. The wall of the embryonic coelom is used in the formation of different organs. The mixocoel in cockroach is obliterated by a loose tissue called *fat bodies*. The rest of the space is occupied by the digestive, excretory and reproductive organs. The blood flows through the mixocoel and for this reason the mixocoel is also called *haemocoel* and the circulating fluid is called *haemolymph*. Two types of cells are present in the fat bodies—one type is binucleated and the other type is with an elongated nucleus. These cells act as storehouse of reserve food which remain in the form of glycogen and are used during starvation.

Alimentary system

The alimentary sytem, which is responsible for nutrition includes *alimentary canal* and *digestive glands* (Fig. 16.54).

ALIMENTARY CANAL. The alimentary canal is about 6·7 cm in length. It is divisible into three distinct regions, (1) *Fore gut*, (2) *Mid gut* and (3) *Hind gut*.

(1) FORE GUT. It is also known as *stomodaeum*. It is lined internally by cuticle and includes the *mouth*, *pharynx*, *oesophagus*, *crop* and *gizzard*. The mouth denotes the beginning of the alimentary canal. This aperture leads to a small chamber called the *buccal cavity* between the mandibles and

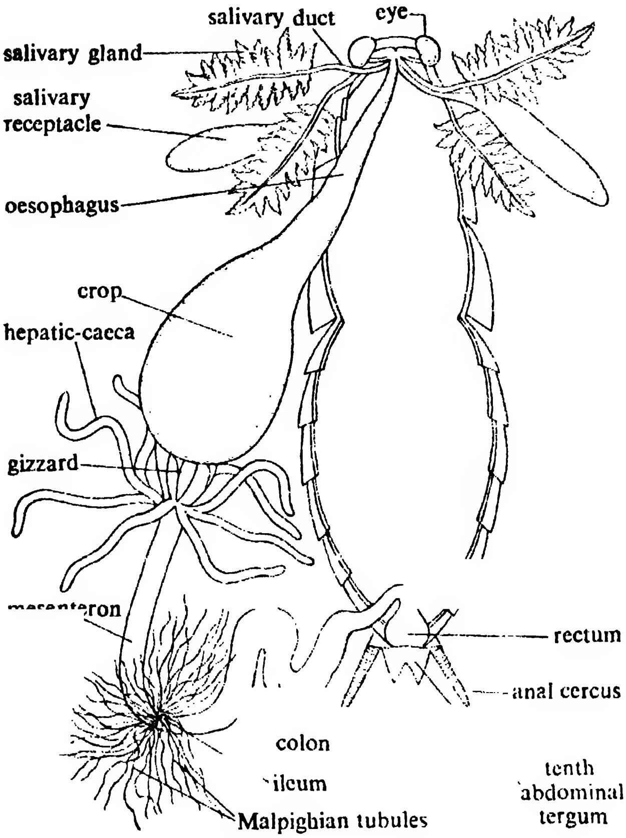


Fig. 16.54. Alimentary system of *Periplaneta americana*.

maxillae on either side. The labrum serves as ***upper lip*** and the labium acts as *lower lip*. A short tongue or hypopharynx is present on the floor of the buccal cavity. The buccal cavity opens into a short *pharynx* which is a small tube. The salivary duct opens within the pharynx near the base of hypopharynx. The pharynx leads into the next part of the fore gut, which is called the ***oesophagus*** and the opening between the two is thick, muscular and guarded by a sphincter. The short and narrow oesophagus is lined externally by a layer of circular muscles and the inner wall contains cuboidal epithelial cells, muscle cells and tracheae. The oesophagus extends up to the prothorax and is followed by the crop. The dilated sac-like crop constitutes the largest part of the fore gut. The wall of the crop is composed of epithelial layer, circular and longitudinal muscle layers. The crop extends within the abdominal cavity and acts as a temporary reservoir of food, where ingested food may be retained for two months. The crop leads into a short thick-walled *gizzard*,• which denotes the last part of the fore gut. It is divided into an anterior and a posterior part. The wall of the gizzard is highly muscular and its anterior part contains in its inner wall six chitinous teeth extending towards the cavity of the gizzard. The posterior part of the gizzard possesses two circular hairy cushions. The teeth are used for crushing the food and the hairy cushions work as sieve to permit only the finer particles of food to go inside the mid gut.

(2) Mid gut. This undivided part of alimentary canal is also known as ***mesenteron***. It is a slender tube having an internal lining of columnar epithelium. Near the junction of the fore and the mid gut, there are eight hollow slender tubes called ***hepatic caeca*** or *digestive diverticula*. The diameter of each hepatic caecum is nearly 1/3rd of the mid gut and histologically it resembles the mid gut. All caeca open within the mid gut and are believed to produce digestive

juices. A loose network of muscle cells is present on the outer wall of the mid gut. In the inner wall, the epithelial cells throw fine filaments within the lumen of mid gut. The junction of the mid and the hind gut is marked externally by the presence of numerous threads called *Malpighian tubules* which are excretory organs.

(3) HIND GUT. It is divisible into following parts—*Ileum*, *Colon*, *Rectum* and *Anus*. The ileum is the first part of the hind gut and has small narrow lumen having epithelial lining. Its outer coat is composed of scattered muscle fibres. The ileum leads to colon, which is broad and slightly coiled. The inner lining of colon is thrown into irregular folds and is formed by slender epithelial cells having a chitinous covering. The colon continues into a small saclike rectum. The inner wall of the rectum is raised in the form of papillae. A special kind of glands called *rectal glands* are present in the rectal wall for absorbing water. Thus the rectum not only stores the residual parts of the food but also helps in osmoregulation. The rectum opens to the exterior through an opening called the anus. The anus is present in between the two *podical plates* and is provided with a sphincter muscle.

DIGESTIVE GLANDS The *salivary glands*, the *inner lining of mid gut* and *hepatic caeca* are the digestive glands of cockroach. A pair of salivary glands lies one on each side of the thoracic cavity. Each gland consists of two leaf-like diffused lobes and a reservoir. The secretory lobes, reservoirs and their ducts together constitute the *salivary* *apparatus* (Fig. 16.55). The lobes of the salivary gland open within the reservoir. From each reservoir a salivary duct runs anteriorly. The salivary ducts of two sides unite to form a common duct which runs along the oesophagus to open into the pharynx and near the base of hypopharynx. Each lobe of the salivary gland is made up of secretory *acini*, which are made up of two types of cells: (*a*) Cells which are packed with secretory granules. Under electron microscope, the endoplasmic reticulum of the cells appears to be distinct at the time of granule formation, (*b*) Cells with an intracellular duct (lined by *chitin*) and with numerous microvilli. These cells have very little secretory granules but abundant mitochondria, coarse endoplasmic reticulum and vesicular bodies. The internal lining of the mid gut and the hepatic caeca also produce digestive juices.

MECHANISM OF NUTRITION. The cockroaches are omnivorous. The food is procured by the maxillae and is cut into pieces by the mandibles. Within the buccal cavity, the food comes in contact with saliva and passes through the oesophagus into the crop. Both peristalsis and antiperistalsis take place in the crop. Such activity of the crop is more intense in males than in females. The passage of food from the crop to the gizzard depends upon the ingested fluid. From the crop, the food passes to the gizzard, where the cuticular teeth crush the food and the hairy cushion permits only finer particles to enter the mid gut. The lining of mid gut and hepatic caeca act both as secretory and absorbtive areas. Following enzymes are present in the secretion of these regions—*amylase*, *maltase*, *invertase*, *lactase*, *β-glucosidase*, *protease* and *lipase*. The *cellulase* obtained in the mid gut is synthesised by the micro-organisms residing there. Most of the digested foods are absorbed only in the mid gut. Glucose is absorbed by the caeca. After the absorption of digested food, the rest

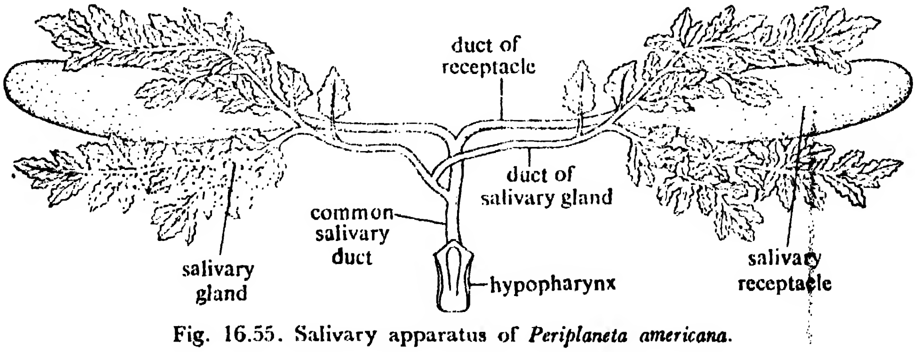


Fig. 16.55. Salivary apparatus of *Periplaneta americana*.

passes within the hind gut, where water and salts are absorbed. Residual matter is temporarily stored in the rectum and are periodically rejected through the anus. Food requires nearly 33 hours to travel the entire length of the alimentary canal.

It may be mentioned here that from the junction of gizzard and mid gut the epithelial cells constantly throw membranous structures called *peritrophic membrane* of uncertain function. These membranous structures are torned up in the anterior region in structures indicates that probably peritrophic membranes from mid gut mix up with saliva at the time of regurgitation.

Respiratory system

The respiration in cockroach is aerial. Our knowledge about the respiratory structures in cockroach is based primarily on the findings from *Blatella*, because little is known about the same in *Periplaneta americana*. The respiratory system (Fig. 16.56) includes (*a*) Ten

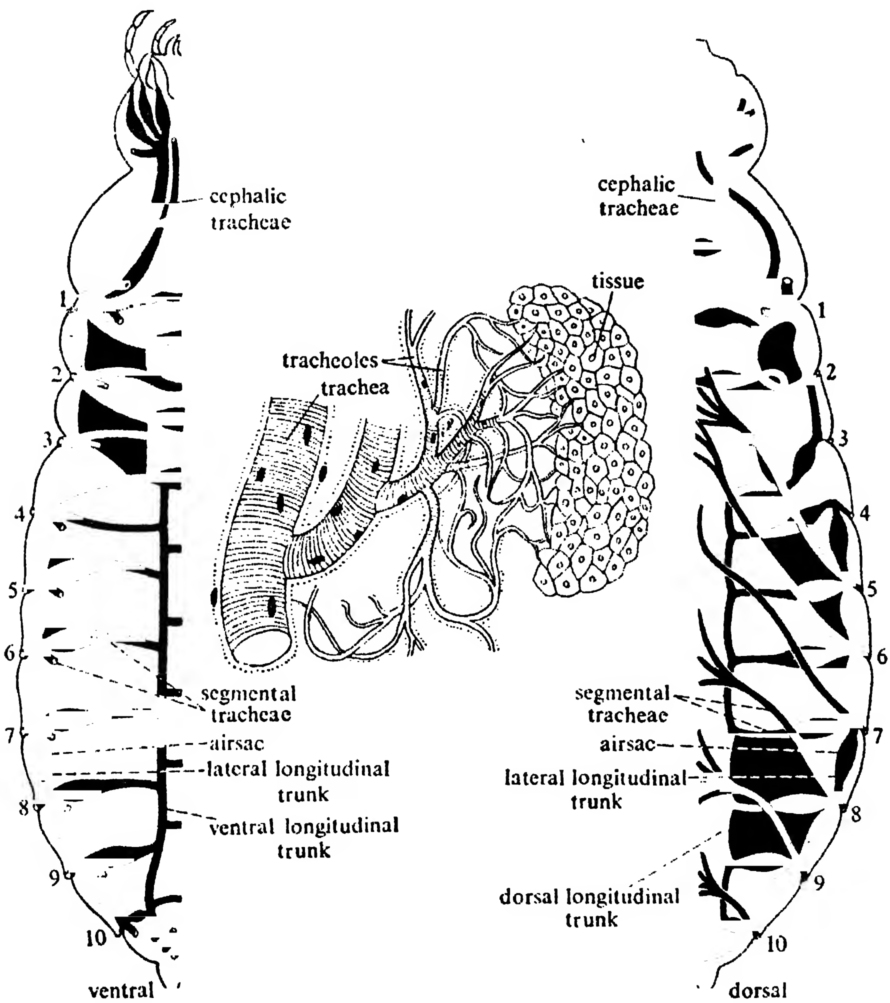


Fig. 16.56. Tracheal system of *Periplaneta americana*. The figure in the middle illustrates the extensive branching of tracheae within the tissues.

of the hind gut by the internal spines. Electron microscopic studies have revealed that the peritrophic membranes are made up of several layers and resemble the structures present in saliva. Such similarity

pairs of *spiracles*, (*b*) three pairs of *longitudinal trunks*, (*c*) several segmental *tracheae* and (*d*) branched *tracheoles*.

Ten pairs of spiracles are present on the lateral sides of the body. Each spiracle is

bounded by an annular sclerite having a filtering apparatus formed by the bristles to eliminate dust particles from the inflowing air. The first pair of spiracles is the largest and is present on the mesothorax. The second pair is on the metathorax and the remaining eight pairs are on the first eight abdominal segments. The mesothoracic spiracle has two lips— the anterior lip is rigid and the posterior lip is movable. The two metathoracic lips are united ventrally. No lip is associated with the abdominal spiracles. The thoracic spiracles open directly within the segmental trachea, but the abdominal spiracles open first within a chamber called atrium and from this chamber segmental tracheae originate.

Three longitudinal tracheal trunks are present on each side of the abdominal cavity. The dorsal and ventral longitudinal trunks are present near the middle line and the lateral longitudinal trunk is present on the lateral side of the abdominal cavity. Each lateral longitudinal trunk is divisible into two parts—the anterior part is present between mesothoracic, metathoracic and first abdominal spiracle and the posterior part extends from second abdominal spiracle to eighth abdominal spiracle. Each dorsal and ventral tracheal trunk originates from a trachea given by first abdominal spiracle, extends up to a segmental branch from eighth abdominal spiracle. Six tracheae originate from each mesothoracic spiracle which supply head, prothorax and mesothorax. From the remaining spiracles on each side three segmental tracheae are given. The longitudinal trunks and the segmental tracheae are swollen at several places and are known as air sacs. From tracheae arise the tracheoles which branch extensively within the tissues.

Large tracheae are internally supported by a spiral ring of chitin, called *taenidia*. In addition, chitinous fibrils of 10 to 30 nm thickness and an epicuticle of lipoprotein nature lines the lumen of the trachea. The lumen of trachea is often seen to be filled up with a substance of unknown nature. Smaller tracheae and tracheoles are devoid of taenidia and other chitinous structures. The opening of each tracheole within the tissue is immersed within the body fluid which conveys respiratory gases to and from the cells.

Mechanism of respiration. During intake of air the abdominal muscles relax to open the anterior four pairs of spiracles, through which air rushes in. The air reaches up to the intercellular spaces through the tracheoles. During expiration, the abdominal muscles contract to drive the air out of tracheal spaces through the last six pairs of spiracles. According to another view, air flows in and out through all the spiracles and probably there is no direct circulation of air along the longitudinal tracheal trunks. The working of spiracles is under the control of central nervous system. The cockroaches can close all the spiracles and may suspend its respiratory activity for a considerable period of time. The opening and closure of the spiracles depend upon the carbon dioxide concentration. Usually the exhaled air contains 4% of carbon dioxide and if there is slight increase in its concentration rapid ventilation movement starts. The width of the spiracular opening increases with the rise of temperature from 20°–33°C.

Circulatory system

The circulating fluid is called *blood* or *haemolymph*. It contains a colourless fluid called *plasma* in which are suspended many *haemocytes*. Following particulars are known about the blood of cockroach:

Sp. gravity—1·029 (in nymph)
Total volume—19% of the body weight (in 24 hrs. old nymph)

Salts present—
Sodium—246 mg per 100 g
Potassium—67 mg per 100 g
Calcium—17 mg per 100 g
Citrate—0·73 mM

Lipoids present—Phospholipids, Sterols and Triglycerids

Carbohydrates present—
145 mg per 100 g blood (before flight)
250 mg per 100 g blood (after flight)

Proteins and amino acids—
Total protein—740 mg nitrogen per 100 ml of blood
Amino acids—Alanine, Cystine, Glutamine, Glycine, Leucine, Methionine, Proline, Serine, Tyrosine and Valine

Other substances—
Uric acid—14·3 mg per 100 g of blood (before flight)
22 mg per 100 g of blood (after flight)

Chitinase—Fairly strong
Glucosidase—traces

The total number of haemocytes in a 24 hours old adult is 9 millions. The haemocytes are usually uninucleated but in pathological condition they may be multinucleated. Three types of haemocytes are known in cockroach—*Prohaemocytes*, *Transitional haemocytes* and *Large haemocytes*. (1) Prohaemocytes—They are small (6–9 μm in diameter) actively dividing cells. The population of these cells is 23% of the total haemocytes. The nucleus is fairly large in comparison to the basophilic cytoplasm. The nucleus contains much chromatin materials and divides by mitosis. These cells are phagocytic in nature. (2) Transitional haemocytes—They constitute 68% of the total haemocytes. Each cell is 9–18 μm in diameter and is phagocytic in nature. These cells divide mitotically only under special condition. (3) Large haemocytes—These cells are 18–23 μm in diameter. Each cell has a nucleus with distinct nucleolus and a network of chromatin material. The cytoplasm shows very weak basophilic stain.

According to the work of Jones (Anat. Record, 128, 571, 1957), there are only two types of haemocytes in *Periplaneta americana*. They are *plasmatocytes* and *coagulocytes* or *cystocytes*. The plasmatocytes constitute 60–95% of total haemocytes. These cells are polymorphic, amoeboid and have spindle-shaped inclusions. The number of coagulocytes varies and the nuclei are large and round. The intranuclear material is bar-shaped.

The blood of cockroach, which is free from the burden of carrying oxygen, serves following functions: (1) Transportation of dissolved substances. (2) Transmission of hydrostatic pressure from one end of the body to the other. (3) Acts as a reservoir of water. The haemocytes which are present in the blood are responsible for phagocytosis, coagulation and wound healing. During phagocytosis, the haemocytes engulf invading micro-organisms or decaying tissues. After phagocytosis, certain haemocytes fully laden with ingested materials aggregate together. A few haemocytes form a capsule around them. The coagulation is the result of dual role of haemocytes and plasma. The process begins with one of the proteins in plasma and probably it is the lipoprotein which reacts to form a network. According to one view, the coagulocytes, being disfigured, break open to release certain granules in the plasma around it. The plasma precipitates around the haemocytes to form islands of coagulated bodies. Another view about the process of coagulation explains that in the beginning some haemocytes round up and throw thread-like pseudopodia which become sticky and thus lead the cells to agglutinate. The plasma material around them precipitates and the entire island dries up to become hard and ultimately black. At the time of wound healing, the haemocytes move towards the injured site and form a clot. After 8–10 days the adjoining epithelial cells start to enlarge and invade the haemocyte mass. The mass splits into an inner and an outer layer. The inner layer continues as a connective tissue layer and after a year becomes fibrous. The outer layer disintegrates and becomes melanised. The epithelial cells form the epidermis.

The *heart* of cockroach is an elongated tube, placed along the mid-dorsal line of thorax and abdomen. The wall of the heart is composed of outer connective tissue and median muscle cells. The cavity of the

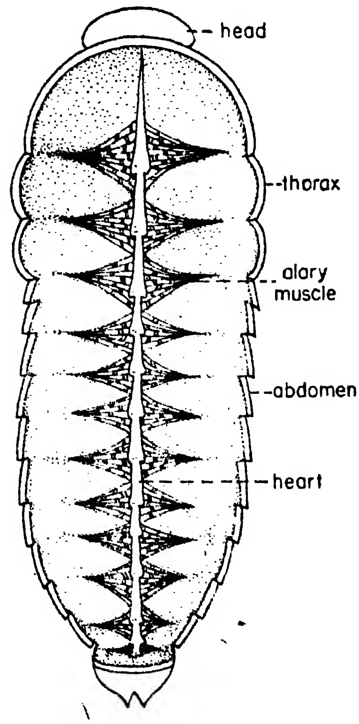


Fig. 16.57. Showing the structure of heart of *Periplaneta americana*.

heart is lined by the sarcolemma of median muscle cells. The heart is enclosed within a pericardial sinus, the wall of which has segmental bundles of *allary muscles* (Fig. 16.57) and a dorsal fenestrated *diaphragm*. At its anterior end, the heart continues as an *aorta*, which branches within the head region. In each segment, heart sends a pair of *segmental excurrent arteries*. The aorta and segmental arteries finally open within the haemocoelomic spaces. From haemocoelomic spaces the blood returns to the *pericardial sinus* of the heart through several minute apertures. The blood, collected in the pericardial sinus, enters the lumen of the heart through 12 pairs of openings called *ostia*. These openings are present one pair in each segment on the ventro-lateral sides of the heart. The heart beats at the rate of 100–120 per minute at 27°C. A complete circulation of blood through the body takes 30–60 minutes.

Excretory system

Near the junction of the mid gut and hind gut, there are numerous (70–120) thread-like, blind tubes, called *Malpighian tubules*, which remain arranged in six bundles. Each bundle contains 15–20 tubules and each tubule has a surface area of 2200 sq. mm. The proximal end of each tubule opens within the lumen of the gut and the distal blind end extends within the haemocoel. The tubules are of two kinds—one kind takes darker silver nitrate stain than the others. The metabolic wastes which are collected from the haemocoelomic fluid are finally drained within the cavity of the hind gut. Opinions differ regarding the nature of excretory substances eliminated by the tubules. According to one view, various nitrogenous substances like urates, uric acid are removed by the tubules along with excess of water. But another view holds that the tubules are only osmoregulatory in function and thus do not remove nitrogenous substances. In addition to the Malpighian tubules, the lining of the hind gut also has excretory function and the rectal papillae in the wall of the rectum regulates the exit of water. The urine is finally ejected with the faeces.

Mechanism of Excretion: Distal part of tubules are secretory, that pours nitrogenous urates of K, Na in solution into the lumen of tubules through osmosis where uric acid precipitates as crystals. Proximal part of tubules are absorptive, that takes out water and inorganic base as bicarbonate which in turn returns to blood (Fig. 16.58).

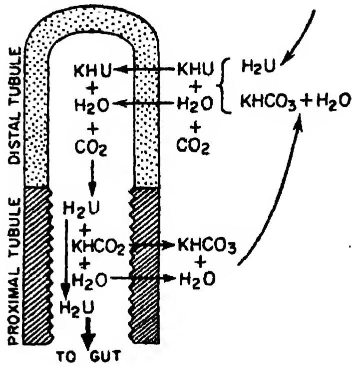


Fig. 16.58. Showing the role of different parts of Malpighian tubule in *Periplaneta americana*.

Nervous system

The nervous system of cockroach includes (*a*) *Central nervous system*, (*b*) *Peri-*

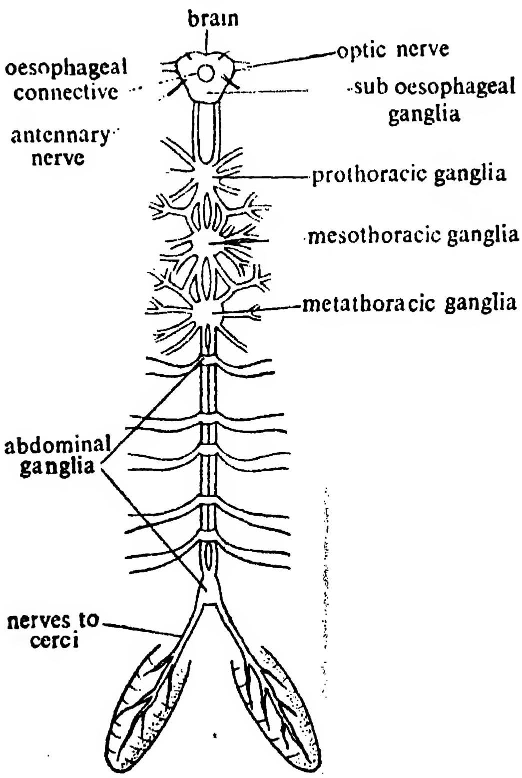


Fig. 16.59. Nervous system of *Periplaneta americana*. This diagrammatic drawing does not include all the peripheral nerves.

pheral nervous system, (*c*) *Sympathetic nervous system* and (*d*) *Sense organs*.

(*a*) CENTRAL NERVOUS SYSTEM. The central nervous system (Fig. 16.59) consists of several specialised parts which control the working of the different structures of the body through the peripheral nervous system. Each of the specialised parts of the central nervous system is discussed below:

1. BRAIN OR SUPRA-OESOPHAGEAL GANGLIA. These are paired and large ganglia, present in the posterior side of the head region and on the dorsal side of the oesophagus. Each ganglion consists of a bilobed *protocerebrum*, a *deutocerebrum* and *tritocerebrum*.

2. SUB-OESOPHAGEAL GANGLION. This ganglion is present in the mid-ventral region of the head and just ventral to the oesophagus. It is formed by the fusion of two ganglia.

3. CIRCUM-OESOPHAGEAL CONNECTIVES. These are short and broad, paired nerves which originate one from each supra-oesophageal ganglion and encircle the oesophagus to unite with the sub-oesophageal ganglion. The two connectives are connected by one large and one small *transverse commissure*.

4. VENTRAL NERVE CORD. It is formed by two solid nerves, which begin from the posterior end of the sub-oesophageal ganglion and run posteriorly along the mid-ventral line of the body cavity. In each thoracic segment it bears a prominent ganglion and in the abdomen there are six abdominal ganglia. First four abdominal ganglia are present one in each of the first four abdominal segments. The fifth abdominal ganglion is present near the junction of fifth and sixth segments. The sixth abdominal ganglion denotes the termination of ventral nerve cord. It is twice the size of other abdominal ganglia. This last abdominal ganglion is more or less present on the eighth segment.

(*b*) PERIPHERAL NERVOUS SYSTEM. These are nerves which are given out from the ganglia of the central nervous system. The name and distribution of different peripheral nerves which are given from the brain and sub-oesophageal ganglia are shown in the enclosed table (Table 2—Arthropoda).

TABLE 2—ARTHROPODA

Particulars about the peripheral nerves from brain and sub-oesophageal ganglia of cockroach

NAME OF THE NERVE	ORIGIN	DISTRIBUTION
1. Dorsal-tegumentary	In between proto- and deutocerebrum.	Mechanoreceptors and thermoreceptors on the vertex and frons.
2. Ocellar	From protocerebrum.	Ocelli.
3. Dorsal cardiac	Do.	Corpus cardiacum.
4. Optic	Do.	Compound eye.
5. Antennal	From deutocerebrum.	Antennary sense organs and muscles.
6. Dorsal deutocerebral	Do.	Three large extrinsic muscles.
7. Ventral deutocerebral	Do.	Ventral extrinsic antennal muscles and sensory hairs at the antennal socket.

TABLE 2—ARTHROPODA (contd.)

NAME OF THE NERVE	ORIGIN	DISTRIBUTION
8. Medio-frontal connective	From deutocerebrum.	Frontal ganglion.
9. Main cardiac	Do.	Posterior part of corpus cardiacum.
10. Lateral frontal connective	From tritocerebrum.	Frontal ganglion.
11. Labral	Do.	Sensory areas of clypeus and labrum.
12. Lateral integumentary	Do.	Sensory areas of gena.
13. Ventral cardiac	Do.	Corpus cardiacum.
14. Hypopharyngeal	From sub - oesophageal ganglion.	Hypopharyngeal muscles and hypopharynx.
15. Corpus allatum nerve	Do.	Corpus allatum and prothoracic gland.
16. Mandibular	Do.	Hypopharynx and mandible.
17. Maxillary	Do.	Maxillary muscles and palps.
18. Labial	Do.	Labial muscles, ligula and labial palp.
19. Cervical	Do.	Cervical muscles.
20. Prothoracic gland nerve	Do.	Prothoracic gland.

Each thoracic ganglion has eight pairs of nerve roots. With the first pair the ventral nerve cord communicates. The remaining seven pairs of thoracic nerves supply the muscles of the thoracic segment, legs and wings. The metathoracic ganglion in addition, sends peripheral nerves to the first abdominal segment. Each of the first five abdominal ganglia sends out pair of stout nerves to supply different parts of the abdominal segment posterior to it. The sixth abdominal ganglion sends out seven to eight pairs of nerves to the different structures present in the seventh, eighth, ninth and tenth abdominal segments.

(*c*) SYMPATHETIC NERVOUS SYSTEM. It is represented by a slender ganglionated sympathetic nerve, which begins from circum-oesophageal connectives to innervate the involuntary muscles of the alimentary canal.

(*d*) SENSE ORGANS. The sense organs of cockroach may be grouped according to their functions as *mechanoreceptors*, *photoreceptors*, *thermoreceptors* and *chemoreceptors*. In addition, another kinds of receptors, for responsing to humidity changes, are recorded in the cockroach, *Blatella*. These are called *hygroreceptors*.

MECHANORECEPTORS. Following sensory structures are considered as mechanoreceptors because they are concerned with the reception of stimuli in the form of touch, pressure, vibration and air current.

(*a*) *Cuticular hairs*. These are present in the cuticle either in the form of bristles, spines, plates or collection of hairs. *Tactile bristles* are present in the cercus and are

extremely sensitive to touch. *Large spines* on the femur and tibia of leg perform similar function. A collection of hairs, known as *hair plates* are present on certain parts of the body for receiving stimuli in the form of touch. A group of specialised hairs which are lodged in sockets occur in the cercus for receiving air movements and low frequency sounds. These are called *auditory* hairs.

(*b*) *Campaniform stress receptors*. They are present as thick ridges on the segments of the leg, on the labial palps and its adjoining areas. These receptors are believed to respond to different pressure on the cuticular surface.

(*c*) *Chordotonal organs*. These specialised sense organs meant for receiving vibrations are distributed on the legs. These are aggregates of specialised cells which remain arranged either parallelly or in the shape of a fan.

PHOTORECEPTORS. The eyes and ocelli are the two important photoreceptors of cockroach, in addition to the general surface of the body which can also detect light stimuli through cuticular receptors.

(*a*) *Compound eyes*. The position and appearance of the compound eye have already been stated. The external surface of the eye is covered by a transparent cuticle. Each eye is composed nearly of 20,000 visual units, each one of which is called *ommatidium* (Fig. 16.60A). Each ommatidium consists of usual structures, like *lens*, *crystalline cone*, *rhabdome* and *retinular* cells (Fig. 16.60B). The cone is well developed and the rhabdomes extend up to the borders of the cone. The retinular cells are partially stratified and contain rhabdomes in their inner border. These cells are separated by a slender axial canal. The pigment sheaths which separate the ommatidium are non-retractile. Thus only mosaic type of image formation occurs.

(*b*) *Ocellus*. This is also known as simple eye. It is present near the base of antenna as a white area. It consists of outer flattened corneal cells, 3–5 retinular cells and one rhabdome formed by the inner margins of the retinular cells. It was formerly believed that these ocelli are of uncertain functions. Recently the light detecting ability of these structures has been proved. It has been demonstrated that cockroaches can respond to the change of light even when the compound eyes are painted. But it fails to do so after the covering of ocelli.

TEMPERATURE RECEPTORS. The temperature receptive sense organs are present in pads between the first four tarsal segments of the leg.

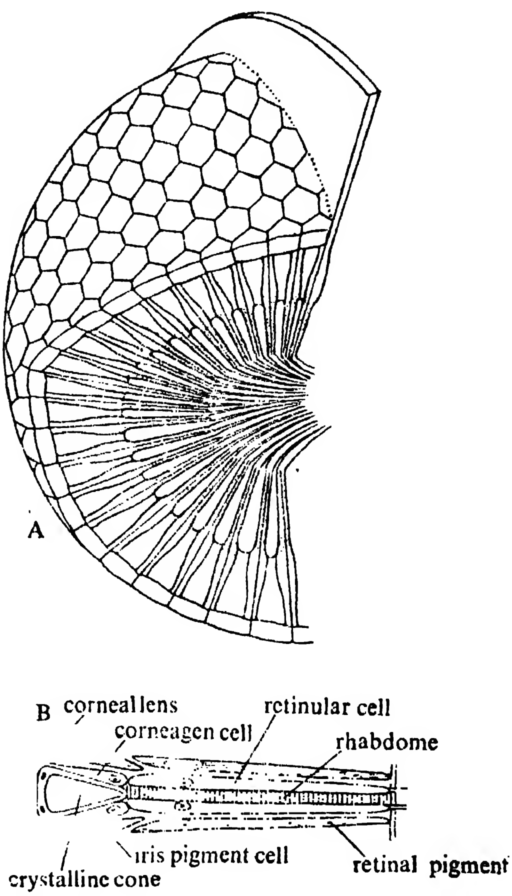


Fig. 16.60. A. Three dimensional model of an insect eye. Lower part is the sectional view. B. Enlarged view of a single ommatidium from insect eye.

CHEMORECEPTORS. These receptors are responsible for detecting chemical stimuli in the form of smell and taste. The long and annulated antennae are beset with two types of sensory structures—thick-walled bristles and thin-walled hairs. These bristles and hairs are responsible for the perception of smell. The tips of the maxillary and labial palps, inner surfaces of the mouth parts and the inner border of the mouth and pharynx possess sensory structures for contact, chemoreception and gustatory responses.

Endocrine system

The body of cockroach contains following endocrine organs *corpora cardiaca*, *corpora allata*, *prothoracic gland* and *cervical glands*. These glands work together with five groups of specialised cells in the brain. Of these five groups, three groups of cells are placed anteriorly and send the first nerve to the corpora cardiaca. The remaining two groups are present at the posterior end and they send the second nerve to the corpora cardiaca.

CORPORA CARDIACA. It is a pair of small, elongated and irregular glands. At the anterior end it encloses the aorta. At the dorsal side it bears a transverse commissure which extends posteriorly as a process to give rise to the aortic nerves. Ventrally, the corpora cardiaca are connected with a rudimentary ganglion and are drawn posteriorly to connect the corpora allata. Each corpora cardiacum receives three nerves—two from the neurosecretory regions of the brain and one from unknown origin. The electron microscopic studies have revealed that the cells of corpora cardiaca have profuse endoplasmic reticulum and prominent secretory granules of 600 nm in diameter. The secretion of corpora cardiaca affects the contractility of muscles lining the gut, the Malpighian tubules and heart. It is believed that the products released by the corpora cardiacum increase the effects of prothoracic glands.

CORPORA ALLATA. This is a pair of small glands present posterior to the corpora cardiaca. Each gland is more or less oval. A transverse commissure connects it with the oesophageal nerve. It has nerve connections with sub-oesophageal ganglion, corpora cardiaca and prothoracic glands. The histology of corpora allata shows the presence of profuse mitochondria within the cells but secretory granules are present in limited areas. The secretion is responsible for following functions: (1) It maintains the juvenile features in the larval stage. (2) It helps in the oocyte formation in adult females. (3) It influences the secretions of secondary sexual organs in both the sexes.

PROTHORACIC GLANDS. At the anterior end of the prothoracic ganglion, lies a pair of rope-like prothoracic glands. A tracheal branch remains associated with the gland. The histology of this gland shows the presence of a central part having 6–8 muscle fibres, which remain enclosed by an outer glandular covering of 4–12 cells deep. The secretory granules are of various sizes. The secretions of prothoracic gland facilitate moulting and after the last moult the prothoracic glands degenerate. It has been experimentally demonstrated that the implantation of two pairs of prothoracic glands in an adult induces it to moult and results into the formation of a giant cockroach.

CERVICAL GLANDS. This is a pair of small oval glands, present in the neck region near the posterior opening of the head. This gland is richly supplied with trachea. The outer part of this gland is composed of large glandular cells and the inner part is made up of small cells with unusually large nuclei. The central part of the gland is occupied by a cavity which traverses within the inner wall. The endocrine nature of this gland has not yet been proved in cockroach but in other insects it is believed to be responsible for producing a hormone to induce moulting. The product which is secreted is called *Periplanetin*.

Reproductive system

Sexes are separate. The members of two sexes may be identified on the basis of their morphological features.

MALE REPRODUCTIVE SYSTEM. The male reproductive system includes a pair of reproductive organs called *testes* (Fig. 16.61). In a cockroach 4·4 cm long, each testis is nearly 1 cm in length. The testis is larger in the young than in older one. Each testis is present in the lateral side of the abdominal cavity and under the terga of fourth and fifth abdominal segments. The sperm cells after originating within the testis run posteriorly through a slender duct called *vas deferens*. The vas deferens from the lateral side of the abdominal cavity curves towards the centre and opens within a sac called *seminal vesicle*. Numerous blind, slender and thread-like structures are given out from the outer wall of the vesicle. These give a mushroom-like appearance and form the *mushroom gland*. The two seminal vesicles open within a common duct called the *ejaculatory duct*. The ejaculatory duct runs up to the reproductive pouch and opens through an aperture called the *male gonopore*. A reproductive pouch is formed near the

ventral side of the ninth and dorsal side of the tenth segments. Numerous accessory structures formed by the modifications of abdominal appendages are associated with the pouch to help in copulation.

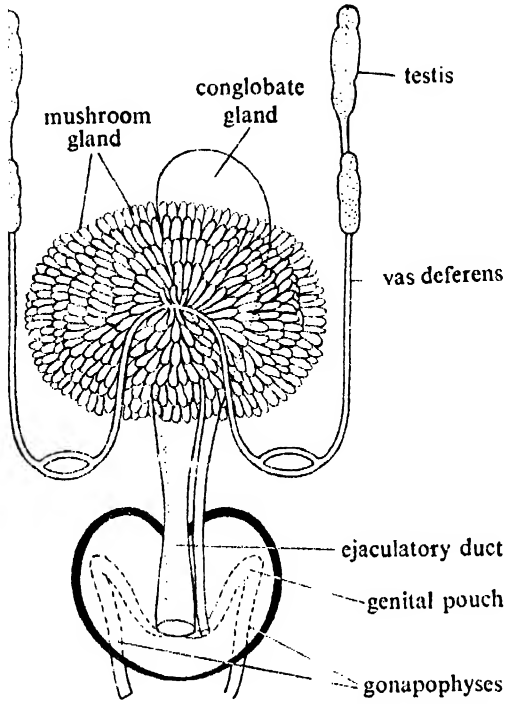


Fig. 16.61. Male reproductive system of *Periplaneta americana*.

Female reproductive system. The female reproductive system includes a pair of *ovaries* and associated ducts, glands and appendages. Each ovary is placed on the lateral and posterior end of the abdominal cavity. Each ovary is made up of eight beaded tube-like *ovarioles* (Fig. 16.62A). Each ovariole is distalo-proximally divisible into six zones (Fig. 16.62B).

Zone 1. The distalmost ligament-like part which connects the ovarioles with the body cavity.

Zone 2. This is the budding zone, where future oocytes are produced.

Zone 3. Here the oocytes grow, but are not arranged in a single file.

Zone 4. This is the longest region where oocytes are arranged in a single line. The distal end has smallest oocyte and the largest one remains at the proximal end.

Zone 5. Broad region of the ovariole which contains oocytes rich in yolk.

Zone 6. This is the proximal part which opens within the oviduct.

From each ovary originates one *oviduct* which is formed by the fusion of ovarioles at the posterior end. The two oviducts unite to form a common chamber called the *vagina* which is placed in the median position. In between the oviducts, a pair of unequal organs called *spermathecae* is present. The two spermathecae open within the genital pouch through an independent median aperture on the ninth segment. A pair of branched tubular glands, called *colleterial glands* opens on the dorsal side of the female gonopore. The left gland is larger than the right one. The genital pouch is formed by the modification of the seventh, eighth and ninth abdominal segments. It is bounded ventrally by the sternum of seventh segment, dorsally by the sternum of ninth and anteriorly by the sternum of eighth segment. The female gonopore opens within the genital pouch at the eighth segment. The opening of the pouch is provided with several chitinous rods.

Development

The female cockroach liberates a smell to attract the male. The male cockroach on receiving the odour, raises its wings and searches the female. During pairing the male protrudes its abdominal segments to fix under the female, thus moving end to end with the female. The pairing continues for an hour. The males which are at least 2–4 days old and females of 4–5 days old are capable of pairing. The pairing of the two sexes results into the transfer of sperm cells from males within the female as small pinhead sized packets called *spermatophores*. Within the body of the female the sperms remain temporarily stored within spermathecae. Sixteen eggs one from each ovariole travel towards the genital pouch through oviduct. Each egg is centrolecithal, i.e. bulk of yolk is confined to the central part of the egg. Thus the cytoplasm with nucleus is restricted to the periphery. After fertilization, the fertilized eggs are enclosed in double row within a case called *ootheca*, which is formed by the secretion of colleterial gland. The ootheca is composed of a protein and

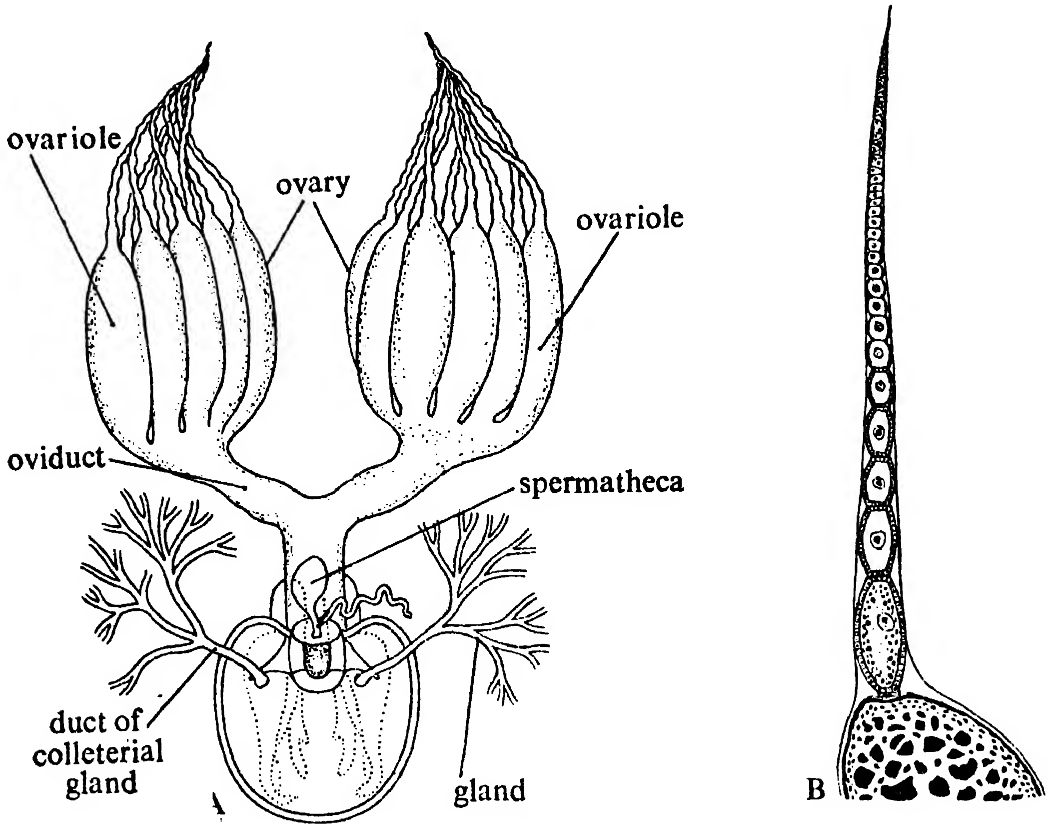


Fig. 16.62. A. Female reproductive system of *Periplaneta americana*. B. Sectional view ovariole to show the linear arrangement of eggs at the different state of maturity.

contains water. The female after laying the egg, fixes it on some suitable object with the help of an oral secretion. The development of the embryo continues within the ootheca and after certain period the young hatches out of the case (Fig. 16.63). The development requires 34–99 days and it depends upon temperature. The rate of hatching is 63% and the young takes five minutes time to come out of the inflated ootheca. After coming out, the young eats the egg membrane. The youngs resemble the adults but are soft, white and without gonads and wings. They are called *nymphs*. The nymphs undergo several moultings. The stage in between two moultings is called *instar*. Wings appear at the end of the last moult. The transformation from nymph to adult takes six to eight months and requires 11 moults in males and 12 moults in females.

Example of the Phylum Arthropoda—*GRASSHOPPER*

The grasshoppers are insects, which have undergone very little specialisation. There are two kinds of grasshoppers—long-horned (having long antennae) and short-horned (with short antennae). The long-horned grasshoppers belong to the family *Tettigonidae* and the short-horned grasshoppers constitute the family *Acrididae*. The well-known short-horned grasshoppers of our country are *Gesonula*, *Poecillocerus*, *Hieroglyphus*, *Tryxalis*, *Attractomorpha*, *Chortogonus*, etc.

Habit and Habitat

The grasshoppers have chewing mouth parts. They occur throughout the world, mainly in grasslands. The locusts are related forms of grasshoppers and are well known for their migratory habits. The metamorphosis is incomplete, i.e. young forms gradually develop into adults and these young stages resemble the adult. It is also called direct metamorphosis.

External structures

The body is slender, elongated and

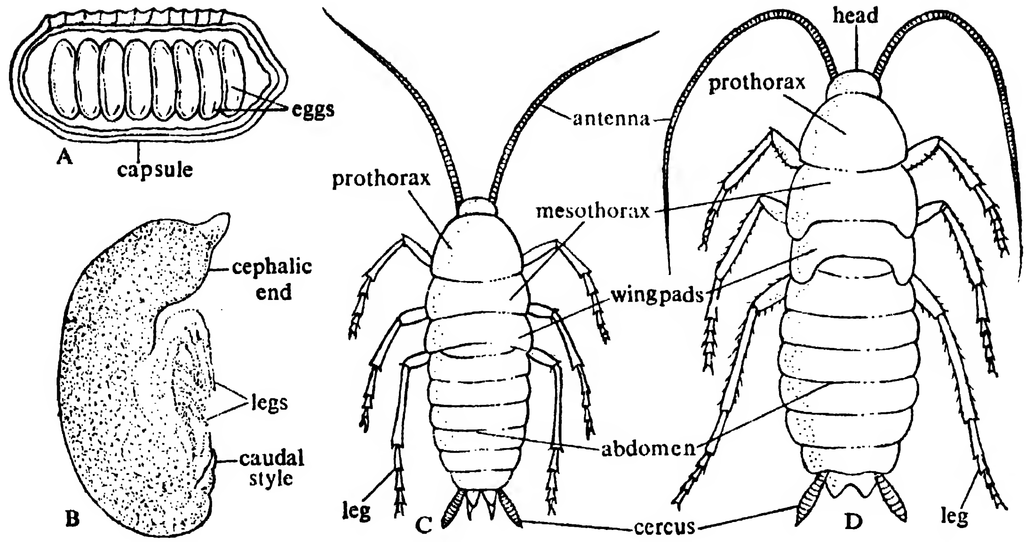


Fig. 16.63. A. Sectional view of an ootheca of cockroach. B. Lateral view of entire egg of cockroach to show the embryo. C. Nymph (early stage) and D. Nymph (late stage) of cockroach.

exhibits perfect bilateral symmetry. It may reach a length up to 8 cm. The colour may be yellowish-green, leaf green or brown. Some forms have varied spots and markings. The segments are distinct. Like that of cockroach the segments are arranged to form three tagmata—*head*, *thorax* and *abdomen* (Fig. 16.64). All the three tagmata are enclosed by chitinous exoskeleton. The exoskeleton of each segment is called a *sclerite* and two adjacent sclerites are separated by a soft suture. Some segments of the body may be fused and the sclerites are indistinct.

A. Head. The head of a grasshopper is covered dorsally by *vertex*, laterally by *genae* or *cheeks* and anteriorly by *frons*. The ventral side of frons is united with the

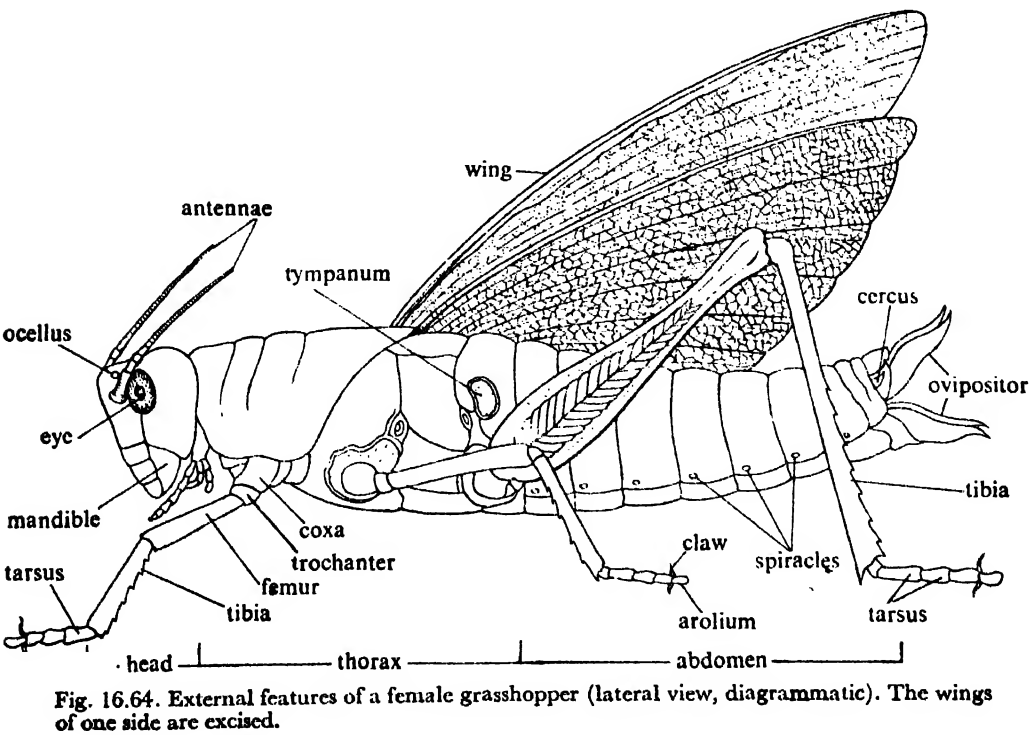


Fig. 16.64. External features of a female grasshopper (lateral view, diagrammatic). The wings of one side are excised.

clypeus. Following structures are present in the head region: (*a*) One pair of large sessile COMPOUND EYES, which occupy the major part of the dorso-lateral region of head. (*b*) Three OCELLI or simple eyes are present, one on the middle of the frons and one on the side of each compound eye. (*c*) One pair of narrow filiform and jointed ANTENNAE is present, one on the anterior border of each compound eye. (*d*) MOUTH is present at the anterior terminal end of the body and directed ventrally. The mouth is provided with mouthparts which are specialised for biting and grinding leaves.

MOUTH PARTS OR TROPHI

The mouth is bounded (Fig. 16.65) by an upper roughly rectangular *labrum* and

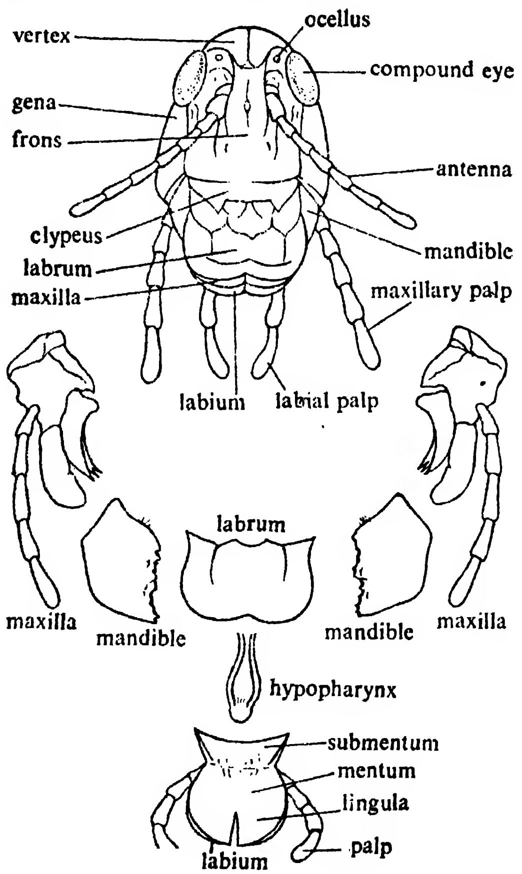


Fig. 16.65. *Upper*. Head of a grasshopper (front view). *Lower*. Mouthparts of a grasshopper (anterior view).

a lower *labium*. The labrum remains attached to the anterior border of the *clypeus*. The labium which appears single is formed by the fusion of two. An elongated tongue or *hypopharynx* remains within the mouth cavity and is attached with the inner side of labrum. The inner broad part of the labium is called *submentum*, middle portion as *mentum* and the two movable anterior parts are called *lingulae*. A pair of jointed *labial palps* arise one from each side of the mentum. The two lateral sides of the mouth are provided with *mandibles*. Each mandible is strongly built. It has serrated inner border. On the outer side of each mandible lies a many-jointed *maxilla*. The proximal part of each maxilla is called the *cardo*, the middle *stipes* and the distal serrated part is *lacinia*. The outer border of stipes bears a *palparifer* and a five-jointed *maxillary palp*. The palparifer carries at one end a round *galae*.

B. THORAX. The thorax has three segments—*prothorax*, *mesothorax* and *metathorax*. The outer covering of the thorax invaginates inside the body to form rigid endoskeleton for the insertion of muscles.

The dorsal covering of prothorax is called *tergum* or *pronotum*. It is large and subdivided into *prescutum*, *scutum*, *scutellum* and *postscutellum*. Lateral coverings are known as *pleuron*. The pleuron is subdivided by a *pleural suture* into an anterior *eipsternum* and a posterior *epimeron*. The ventral side is covered by a single *prosternum*.

The mesothorax is covered dorsally by a single *mesonotum* and ventrally by a *mesosternum*. Each lateral side is covered by pleuron having divisions called *episternum* and *epimeron*.

The metathorax is compact and larger than the other two divisions of the thorax. The exoskeletal coverings are same as in mesothorax, the dorsal one is called *metanotum* and the ventral one is called *metasternum*.

Structures present in the thorax

SPIRACLE. A pair of spiracles are present on the dorso-lateral sides of each meso- and metathorax.

LEG. One pair of legs are present in each thoracic segment. The prothoracic legs arise from the ventro-lateral angle of the body and act to pull the body forward. The mesothoracic legs support the body during walking. The metathoracic legs are the largest and push the body forward during walking and are used for jumping. Each leg consists of similar segments as

that of cockroach. In the males, the third segment of the leg bears rows of chitinous hooks. These hooks are moved with pressure along the hard outer surface of the wing on prothorax to produce a sound. This sound producing organ is known as *stridulatory* organ.

WING. Two pairs of wings are present—one pair on the mesothorax and the other on the metathorax. The wings which remain attached on the dorso-lateral angle of mesothorax are called *fore wing* or *tegmina.* The fore wing is narrow and leathery. The wings at the dorso-lateral angle of the metathorax are called *hind wings.* These wings are broad and membranous. The hind wings are used during flight. At the time of rest, these wings remain covered beneath the fore wings. Each wing is composed of two cuticularised layers with branched tracheal tubes in between. These tracheal tubes are known as *nervures* or *veins.*

C. ABDOMEN. The abdomen is made up of eleven embryonic segments. Of these segments, the anterior seven are easily recognised in adult grasshopper. The posterior segments undergo modifications. These modifications are different in male and female grasshoppers. Each ring-like segment is covered by a dorsal *tergum* and ventral *sternum.* The inconspicuous inter-segmental membranes connect the exoskeletal coverings of the abdominal segments. The dorsal exoskeletal covering of the first abdominal segment is continuous with the same of metathorax. On the lateral surface of the first abdominal segment is present a tympanic membrane for receiving sound stimulus. Each abdominal segment bears a pair of spiracles. Thus there are altogether eight pairs of abdominal spiracles. In males, the tergites of ninth and tenth abdominal segments are united and the sternite of ninth segment is considerably altered The ninth segment bears the *genitalia* which include two pairs of gonapophyses. The outer pair of gonapophyses form the *claspers* and the inner small pair are known as *parameres.* The gonapophyses cover the penis. The sternite of the tenth abdominal segment forms the *subgenital plate* and the tergite of eleventh segment works as *supra-anal plate.* The supra-anal plate bears one pair of *cerci* and two *podical plates.* In females, the sternites of ninth, tenth and eleventh segments are modified to form the genitalia which work as the *ovipositor.* The ovipositor has three pairs of valves. The dorsal pair of valves arise from the ninth and the ventral pair from the eighth segments. The third pair of valves are placed inside to act as a channel for the outlet of eggs. The tergites of these three segments are incompletely united. The last segment bears—one pair of *cerci* (not so large as in males) and a pair of *podical plates*

Digestive system

The digestive system (Fig. 16.66) consists of the *alimentary canal* and *digestive glands.* The ALIMENTARY CANAL is divisible into a *fore gut*, *mid gut* and *hind gut.* The FORE GUT begins from mouth which leads into a small *pharynx.* The mouth is provided with mouth parts for biting and chewing food. In the pharynx the salivary duct opens. The pharynx leads into a narrow *oesophagus* which runs upward to enter into a thin, dilated chamber called the *crop.* The crop is followed by a small tube called *proventriculus* or *gizzard* which possesses in its inner wall chitinous plates raised to

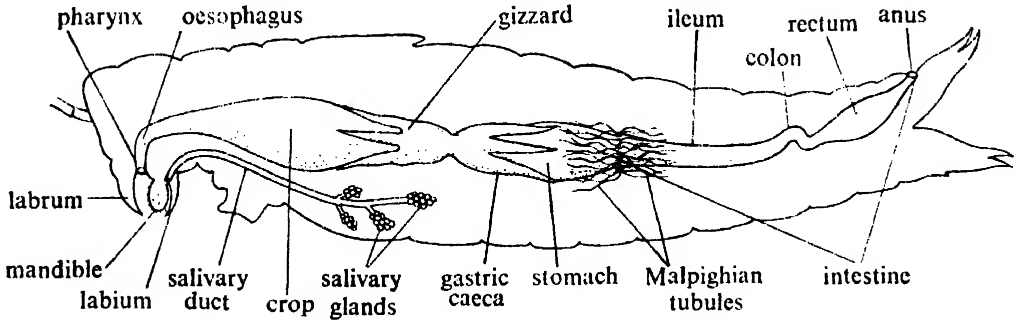


Fig. 16.66. Alimentary system of grasshopper (lateral view).

form teeth. The gizzard completely liquifies the food which then enters into the *stomach* or *ventriculus*. The opening is guarded by a sphincter. The stomach represents the MID GUT and its beginning is marked externally by the presence of six gastric or hepatic *caeca*. Each is attached near the middle of caecum, i.e. each caecum has one anterior lobe and a posterior lobe. The opening between the mid gut and the first part of the HIND GUT, called *ileum* is guarded by a sphincter. This region of attachment between mid and hind gut contains a circlet of numerous slender *Malpighian tubules*. The ileum leads to a slender *colon* which in turn enters to the enlarged *rectum*. The rectum ultimately opens to the exterior through an opening called *anus*.

The DIGESTIVE GLANDS include *salivary glands*, the *lining of the mid gut* and *hepatic caeca* all of which produce digestive juices. The salivary glands are small paired structures present on the outer surface of the crop. The salivary duct opens within the pharynx.

The grasshoppers are leaf-eaters. The mouth parts are used for cutting and crushing the leaf. The saliva moistens the food and at the same time partially digests it. The food remains temporarily stored within the crop and slowly flows into the gizzard. In the lumen of the gizzard the food is fully churned. Then it goes to the mid gut. Lining of the mid gut and hepatic caeca secrete digestive juices. Various enzymes, present in the juices complete the digestion. Absorption takes place in these two areas. The residual matter passes into the rectum. The mineral salts and water are absorbed by the lining of the rectum and the faeces are ejected through the anus.

Respiratory system

Respiration is aerial and the respiratory structures are *tracheae* (Fig. 16.67). There are two *dorsal*, two *ventral* and two *lateral longitudinal tracheal tubes*. These communicate with one another by transversely placed *segmental tracheae*. Some of these connecting tracheae are inflated as *air sacs*. From the trachea arises finer vessels called the tracheoles which form extensive network within the tissues. The inner wall of the trachea is provided with spiral cuticular thickening. Such thickenings are absent in tracheoles. The ultimate opening of the tracheole is immersed within body fluid, which conveys respiratory gases to and from the cells.

The lateral longitudinal vessels communicate with the exterior through ten pairs of spiracles. Of these ten pairs of spiracles, two pairs are on the thorax and the remaining eight pairs are on the abdominal segments. These are placed in a row of ten in each lateral side. Each spiracle is enclosed by a round sclerite called *peritreme* and a *valve* to guard the opening. The valve is provided with muscles and nerves.

During inspiration or taking in of air, the first four spiracles open and the air rushes inside. At the time of expiration, last six pairs open and the air passes out of the body.

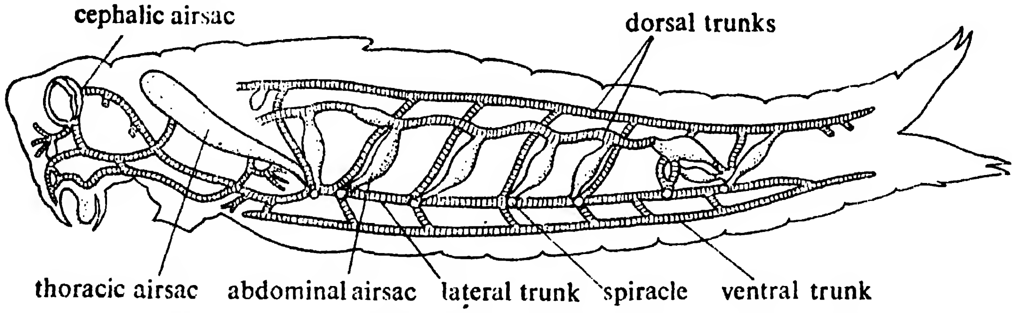


Fig. 16.67. Respiratory system of grasshopper. Showing only a part of the tracheal network, air-sacs and last seven abdominal spiracles.

Excretory system

The excretory organs are in the form of *Malpighian tubules*. These are present near the junction of stomach and ileum. Each tubule is thread-like and internally lined by a layer of striated epithelial cells. The free blind end of these tubules extends within the haemocoel and removes metabolic wastes from the blood. These waste products are finally drained within the

ileum, from where these are removed with the faeces.

Circulatory system

The *heart* is tubular and is placed on the dorsal side of the thoracic and abdominal cavities. It is drawn anteriorly into an aorta (Fig. 16.68). The heart contracts to drive blood anteriorly which flows through the *aorta*. The aorta breaks up into finer branches in the head and thoracic regions and ultimately opens to the haemocoelomic spaces (*Haemocoel*). Through these spaces the blood returns to the posterior part of the body. The deoxygenated blood is finally accumulated within a large haemocoelomic space around the heart called *pericardial sinus*. From the sinus the blood enters the heart through paired segmental openings of the heart called *ostia* (singular—*ostium*). The outer wall of the pericardial sinus is provided with segmentally arranged *allary muscles*. These muscles cause the pericardial wall to contract and force the blood to enter into the heart. The contraction of heart to drive the blood is possible due to the contractile nature of its wall.

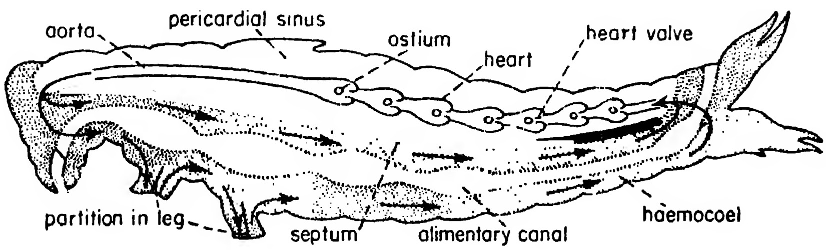


Fig. 16.68. Circulatory system of grasshopper.

Nervous system

The nervous system has three usual divisions—*central nervous system*, *peripheral nervous system* and *sympathetic nervous system* (Fig. 16.69). The CENTRAL NERVOUS SYSTEM consists of BRAIN or SUPRA-OESOPHAGEAL GANGLION, OESOPHAGEAL CONNECTIVES, SUB-OESOPHAGEAL GANGLION and VENTRAL NERVE CORD. From brain paired peripheral nerves are supplied to the eyes and antenna. The sub-oesophageal ganglion supplies nerves to the mouth parts. The ventral nerve cord originates from sub-oesophageal ganglion and runs up to the posterior end of the body along the mid-ventral line. The ventral nerve cord consists of the chains and throughout the length its double structure is visible. The ventral nerve cord along its path bears three *thoracic* and five *abdominal ganglia*. These ganglia send paired peripheral nerves to the muscles and spiracles of the corresponding segment.

The SYMPATHETIC NERVOUS SYSTEM is represented by a thin stomatogastric nerve having oesophageal ganglion and visceral ganglion. It is connected with the brain and supplies branches to the heart and digestive tube.

Sense organs. Following sense organs are present in the body of grasshopper:

(1) ORGANS FOR TOUCH. The structures like antennae, palps, distal segments of legs and cerci bear sensitive hairs which can feel the surrounding.

(2) ORGANS OF SMELL. The many-jointed antennae bear specialised sensory hairs for detecting the smell and thus help in finding the food.

(3) ORGANS OF TASTE. The surface of the palps and mouth parts are provided with special kinds of sensory bodies to determine the taste of food.

(4) ORGANS FOR DETECTING LIGHT. *Ocelli* and *compound eyes* are the two organs for receiving stimuli in the form of light. Each ocellus consists of a lens formed by thick and transparent cuticle and a group of retinular cells. These ocelli are capable of differentiating light from darkness. The structure of compound eye is built up in same plan as that of cockroach. The image formation takes place in the identical way.

(5) ORGANS FOR RECEIVING SOUND. The tergum of the first abdominal segment bears on its each lateral side a circular area for receiving sound waves. It consists of a round chitinous ring on the centre of

which a membrane is tightly stretched. In the inner wall of the tympanum lies a slender auditory apparatus (Fig. 16.70). This auditory apparatus remains attached with its one end to the centre of the tympanum and by the other end to the auditory nerve. The sound waves hitting the tympanum are conveyed to the auditory apparatus to be communicated through auditory nerves.

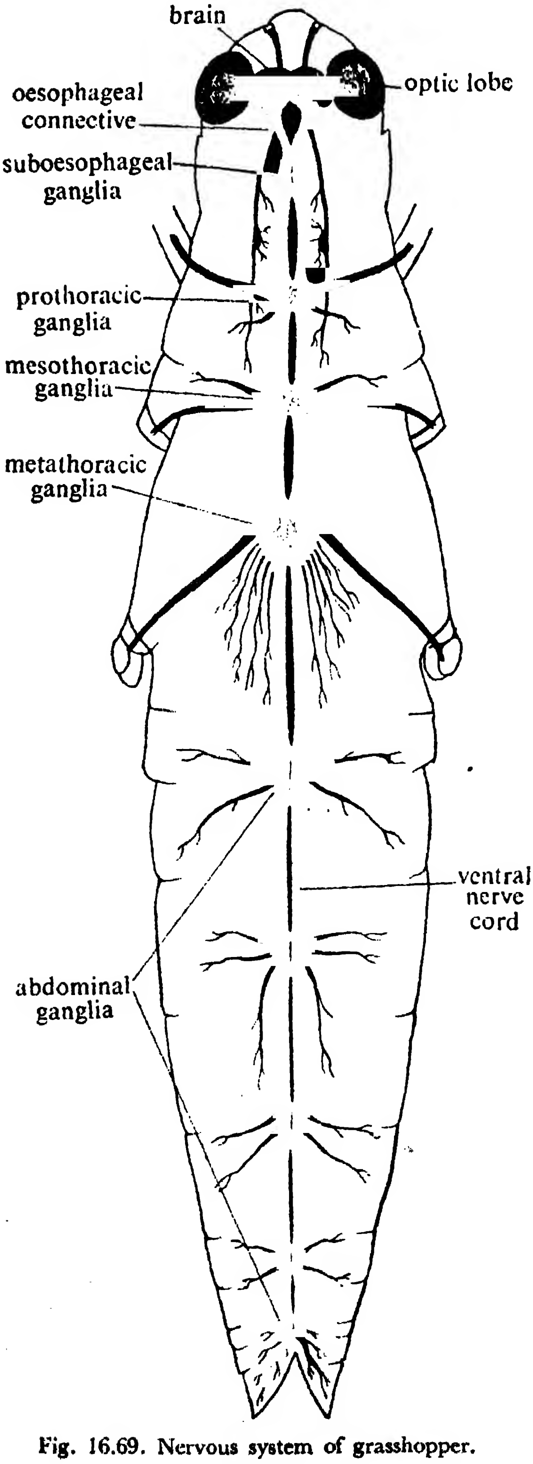


Fig. 16.69. Nervous system of grasshopper.

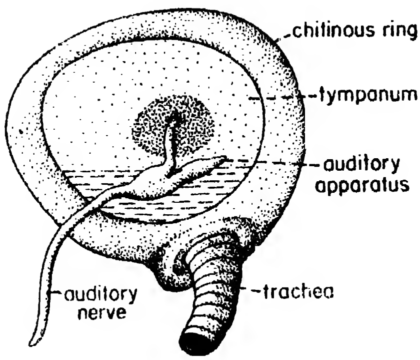


Fig. 16.70. Auditory apparatus of grasshopper.

Reproductive system

Sexes are separate and sexual dimorphism is noted from the disposition of structures present in the posterior abdominal segments.

MALE REPRODUCTIVE SYSTEM (Fig. 16.71A). The male reproductive organs or testes are paired structures placed on the ventral side of the alimentary canal. Each testis is divided into four regions—*Germarium*, *Spermatocyte zone*, *Spermatid zone* and *Spermatozoa zone*. The sperm cells from each testis are carried through a duct called the *vas deferens*. The two vasa deferentia open within an unpaired duct called the *ejaculatory duct* having cuticular lining. The last part of the vas deferens is swollen and is known as seminal vesicle. The ejaculatory duct opens to the exterior through a copulatory organ called *aedeagus* or *penis*. The accessory glands called *mushroom glands* open within the ejaculatory duct.

FEMALE REPRODUCTIVE SYSTEM. (Fig. 16.71B). The female reproductive organs or *ovaries* are paired structures and present one on each side of the alimentary canal. Each ovary is made up of *ovarioles*. Each ovariole has following three zones—*Terminal filament*, *Germarium* and *Vitellarium*. From each ovary reproductive cells or ova pass through a duct called *oviduct*. The two oviducts unite to form a *common oviduct* which opens within a cuticularised chamber called *vagina*. It opens to the exterior through *ovipositor*. The vagina receives

slender ducts from the *spermathecae*, where the sperm cells remain temporarily stored after copulation. The accessory glands, known as *colleterial glands* liberate a foamy product within the vagina. This substance forms a hard structure around the egg after deposition. The eggs are laid and buried within small holes which are dug up by the female with the help of ovipositor (Fig. 16.71C–1).

shedding off of the old exoskeleton. The grasshopper undergoes five moults before becoming an adult. Each phase between two moulting is called an *instar*. As in all other winged insects (excepting Mayfly) no moulting takes place in the grasshopper after the attainment of the adult form.

Economic importance of grasshopper. *As crop pests:* They eat many kinds of vegetation and cause serious damage to major

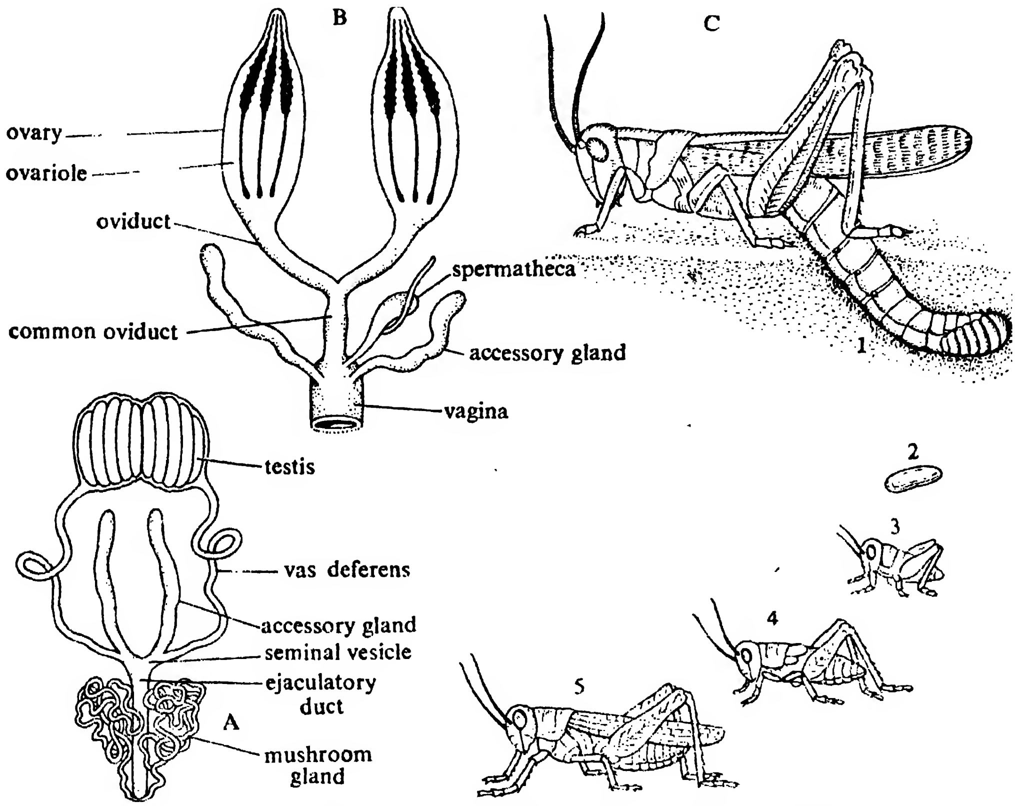


Fig. 16.71. A. Male reproductive system of grasshopper. B. Female reproductive system of grasshopper. C. Egg laying and different stages of development in grasshopper

Development

Early development continues for three weeks and then remains suspended for a certain period of time. This phase of arrested growth is called *diapause;* at this phase the individual tides over the adverse environmental condition. After the return of favourable period, growth resumes and young grasshopper emerges out of the egg shell. It is then known as a *nymph*. Its body resembles the adult in all respects excepting the proportion of different parts (Fig. 16.71C, 2–5). Further growth involves *moulting* or

crops like paddy, wheat. During favourable conditions and lack of enemies they can fly in huge number (June–July) causing swarms called *Plague of grasshoppers*.

As food: The eggs, nymphs and adults provide good food for several predatory insects, spiders, frogs, reptiles, birds, etc. sometimes they are used by human as food and fish bait. Grasshopper is used in Japan, Phillipines, Mexico as dish of delicacy. They are commonly eaten by North American Indian and certain primitive tribes. The Greeks grind them by mortars and the powder is then stored to be used as food.

Control of grasshopper

Natural control: Eggs are eaten by some beetles, bee, flies, moles, mice; nymphs by robber flies, digger wasps; both nymphs and adults by predatory large insects, frogs, reptiles, birds and mammals. Flesh flies (*Sarcophaga*) lay maggots on adults and tachinid flies lay eggs on adult and nymphs of grasshopper, thus maggots bore their way into hosts bringing bacteria and fungal diseases which may cause death.

Physical control: During winter, the soil is exposed to sun by ploughing. Developing ones thus wither away in sun light or eaten up by birds.

Chemical control: Various insecticides are used in the form of dust, spray or poisoned bait. Insecticides like aldrin, dieldrin, chloradane, toxaphane are used very often. Methoxychlor is also now used for protecting vegetables and crop plants as it is a non-residual type of insecticide and is less harmful to man and domesticated animals.

GESONULA—a typical representative of GRASSHOPPER

Gesonula punctifrons is a common short-horned grasshopper available in different parts of West Bengal and adjoining States. Because of its easy availability, *Gesonula* is selected as a type specimen to study the anatomy of grasshopper in general. *Gesonula* has many features common with the grasshopper already described. However, the following description will be helpful to the students as a guide line in their practical work.

Digestive system

Fig. 16.72A shows the basic organisation of the alimentary canal of *Gesonula*. There are six *caeca*. The caeca are attached with the gizzard part of the alimentary canal by their mid-posterior ends. The posterior free lobe of each caecum is short while the anterior free lobe is longer and is about three times in length than its posterior counterpart. Inside the gizzard or proventriculus there are six chitinised V-shaped *teeth* which correspond with the caecal opening into the gizzard. There are six longitudinally disposed *rectal pads* inside the rectum, which help in the absorption of water. Numerous fine greenish yellow thread-like structures are observed at the junction of the ventriculus and ileum. These threads are called *Malpighian tubules* which are seldom coiled. The tubules form a few distinct bundles which in turn open into the gut separately.

Reproductive system

In Fig. 16.72 A, B and C show the plan of reproductive system of *Gesonula*. The ovarian follicles of both the sides are united medially and are situated dorso-medially. There are a pair of accessory glands at the anterior end of the ovary. The testes, though paired, remain closely adpressed and covered by yellowish connective tissue and thus appear unpaired. It extends from 2–6th abdominal segments. The testes are of 'Fountain type', i.e. the follicles enter in a cluster into the vas deferens near its blunt end. The male accessory glands are 14 pairs inclusive of seminal vesicle. On the basis of their appearance and contents the accessory glands are distinguishable into three types:

(*a*) *White glands:* These are 4 pairs of white glands of more or less equal size and remain filled with milky white secretion.

(*b*) *Hyaline glands:* Eight pairs in number and are of varying lengths containing colourless secretory material.

(*c*) *Opalescent glands:* These are two in number and remain filled with opalescent granules.

(*d*) *Seminal vesicle:* These are paired structures and are highly coiled.

EXAMPLE OF THE PHYLUM ARTHROPODA—
HONEY BEE

Habit and Habitat

There are several kinds of bees. The one which is described here is scientifically known as *Apis mellifica*. The other important species are *Apis dorsata*, *Apis florea* and *Apis indica*. Honey bees are well-known for their organised social life and great economic importance. The nest of the honey bee is known as the *bee-hive*. It is commonly seen on tall trees and ceilings of houses. The practice of rearing bees in artificial hives for honey and wax is long known to man and is followed throughout the world.

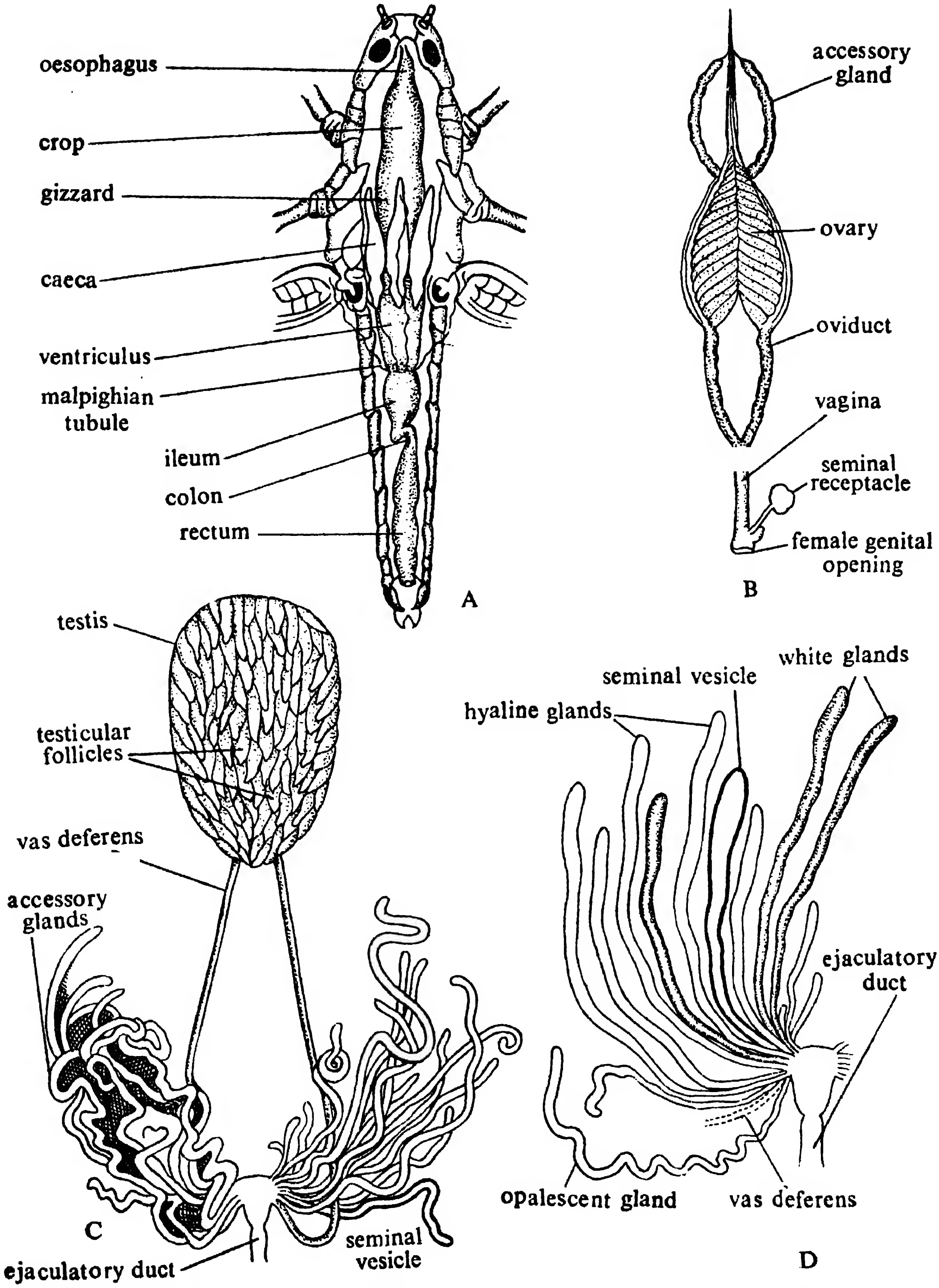


Fig. 16.72. Anatomical sketches of *Gesonula punctifrons*. A. Digestive system. B. Female reproductive system. C. Male reproductive system. D. Enlarged view of accessory glands of male. (Courtesy: Dr. Himangshu Banerjee).

Polymorphism in honey bee. Thousands of bees (50,000 to 80,000) which live in a hive are of three different forms—(1) workers, (2) drones and the (3) queens (Fig. 16.73). The phenomenon of the existence of several morphological forms in a

species is known as polymorphism. So, the bees are polymorphic species.

Worker bee. The size of worker bee is small but they constitute the majority in a hive. Each worker bee in its life time acts in different capacities—cleaner, nurse, builder, technician, soldier and porter.

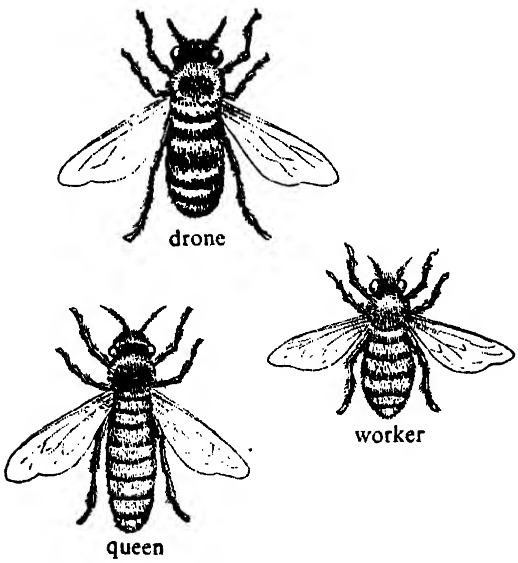


Fig. 16.73. Three different forms in a colony of honey bees.

Drone bee. Little larger than the workers, but are idle and noisy. They come out of the hive only at the time of nuptial flight.

Queen bee. Generally a single matured queen is present in each hive. The size is very large specially the abdomen. It is responsible only for laying of eggs.

External structures

Three tagmata of the body, namely, *head*, *thorax* and *abdomen* are provided with certain specialised structures to help it in its peculiar habit.

Head. The triangular head (Fig. 16.74) contains (1) three ocelli in the middle, (2) two well-marked compound eyes, (3) two short, many-jointed antennae and several appendages around the mouth which are of *rasping* and *lapping* type. These mouth parts include—(*a*) *Mandible.* These paired spoon-shaped structures are very strongly built in worker bees and are used at the time of making of combs. (*b*) *First maxilla.* Each of the paired maxillae includes a *lamina* or *galea* on a basal piece which is composed of two elements—*stipes* and *cardo*. The *maxillary palps* are poorly developed. (*c*) *Second maxilla.* These paired appendages form the lower lip. It is well developed in the workers. The proximal parts of the two maxillae are united. From the outer side of each second maxilla hangs a long *labial palp*. The inner side may be splitted into two parts—*glossa* and *paraglossa*. Two glossae, one from each second maxilla, are united to form the tongue or *ligula*. The distal spoon-like tip of the tongue is called labellum and it has

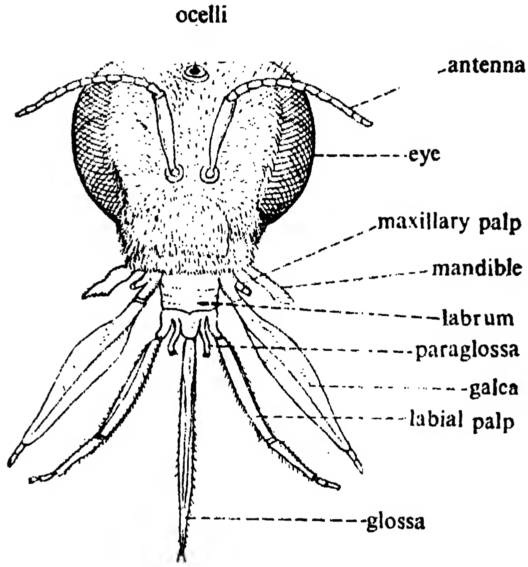


Fig. 16.74. Enlarged view of the head of honey bee (after Thomson).

a ventro-median groove. The paraglossa is firmly united with the base of the ligula. Three parts—labial palps, ligula and paraglossae form an airtight tube for sucking nectar. The elongated mouth parts, while not in use are kept folded.

Thorax. The thorax, as in other insects, consists of three segments—prothorax, mesothorax and metathorax. Each thoracic segment bears a pair of appendages in the form of legs. Two pairs of wings occur as non-appendicular structures. There are two pairs of spiracles—one pair in the mesothorax and the other on the metathorax.

Legs. The legs have the same pattern as that of cockroach but are largely modified for their particular way of life (Fig. 16.75). (1) *Prothoracic legs.* Here the tibia of each

leg is provided with soft hairs called *eye brushes*, which are used for cleaning the pollens and debris from the eye. The stiff bristles known as *pollen brushes* are present on the first tarsal segment to work as antenna cleaner. (2) *Mesothoracic legs*. In addition to pollen brushes of the first tarsal segment, the tibia bears a *wax spine stick* for removing wax from the wax glands. (3) *Metathoracic legs*. The first tarsal segment bears at its inner part *pollen combs*,

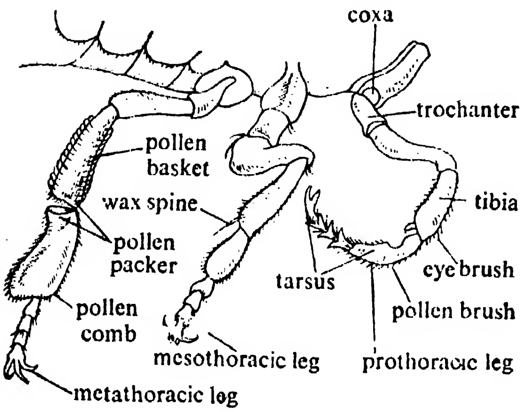


Fig. 16.75. Thoracic legs of a worker honey bee (only one side is shown). Note the difference in structure (after Kimbal).

which are responsible for collecting pollens from the pollen brushes of other legs. A structure called *pollen packers* is present near the junction of tibia and first tarsal segment. This pollen packer is formed by a spiny *pecten* on tibia and a knotched plate called *auricle* on the first tarsal segment. It cleans the pollen combs and deposits the pollens within pollen basket which is placed on the outer side of the tibia.

Wings. Two pairs of wings are placed on the dorsal side of the thorax. The wings are largest in drones and smallest in queens. The wings are structurally same as that of cockroach, but the mechanism of wing action during flight is peculiar and completely different from most other flying animals. The wings instead of mere flapping, perform a speedy rotatory motion. Such action helps the bee to do various movements during flight, e.g. ascending, descending, remaining fixed and also backward movement. Aerodynamically speaking, the flight of honey bee resembles more with the helicopter than aeroplane.

Abdomen. The number of segments in the abdomen are seven in drones but six in workers and queens. In drones, the abdomen is broad but smaller than the wings. In queens the abdomen is elongated and tapering. The abdomen bears several apertures called *stigmata*, which are six pairs in drones and five pairs in queens and workers. The workers bear on the ventral side four pairs of *wax glands* to produce wax. The wax is liberated through minute pores which form scales. In queens and workers the posteriormost end of the abdomen is provided with a *sting* which is connected to the internal *poison gland*. The sting is formed by a dorsal *stylet sheath* and a pair of ventral *lancelets*. These three pieces enclose an inner *poison canal*. At its proximal end the sting has a swollen *bulb* and a pair of *bifid arms*, one on each side of it. The distal tip is beset with spines called *barbs* (Fig. 16.76). Three pairs of plates—

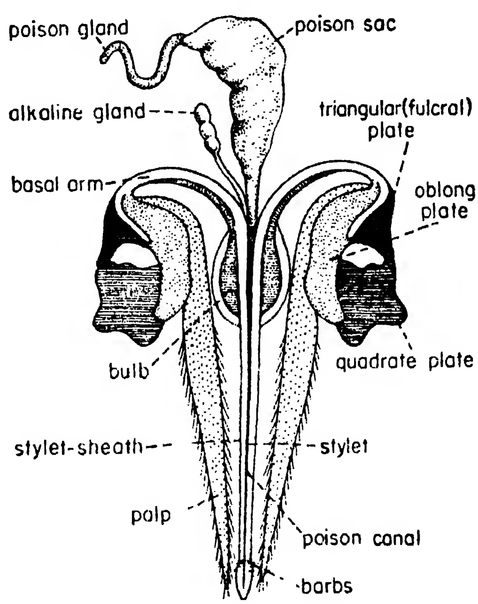


Fig. 16.76. Sting of a honey bee (worker).

oblong, *fulcral* and *quadrate*, remain associated with the sting to act as lever. From each oblong plate arises an elongated palp to enclose the sting. The poison gland is short and slender. Its secretion remains stored in a large poison sac, which opens to the proximal end of the sting near the bulb. In the queen, the sting also acts as an ovipositor.

Digestive system

In addition to the *mouth* and *pharynx*, the alimentary canal consists of

following parts—*oesophagus*, *honey sac*, *chyle stomach*, *small intestine*, *large intestine* and *anus* (Fig. 16.77). Straight and tube-like oesophagus passes through the thoracic region. Within the abdomen the last part of the oesophagus dilates to become a honey sac. The honey sac opens to the chyle stomach. The opening is guarded by a complex stopper. The chyle stomach

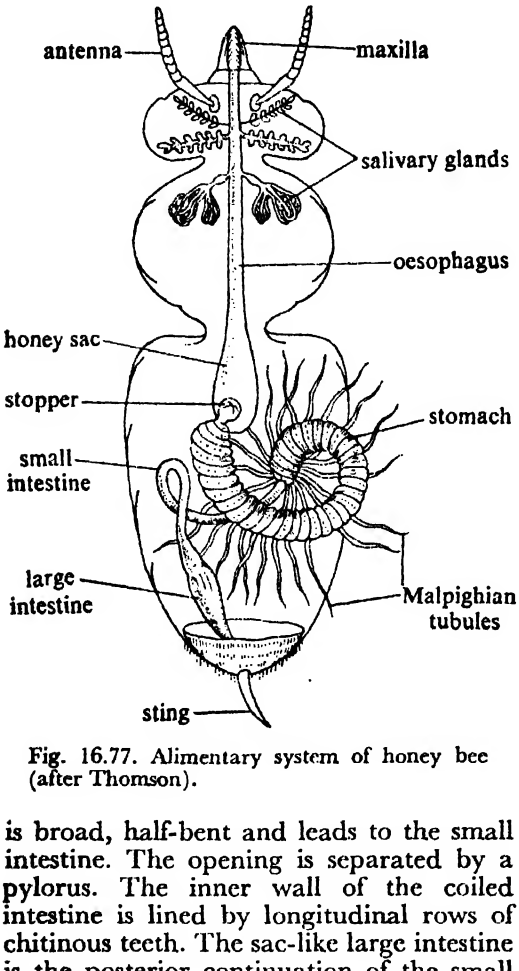


Fig. 16.77. Alimentary system of honey bee (after Thomson).

is broad, half-bent and leads to the small intestine. The opening is separated by a pylorus. The inner wall of the coiled intestine is lined by longitudinal rows of chitinous teeth. The sac-like large intestine is the posterior continuation of the small intestine. The opening between small intestine and large intestine is guarded by valves of six plates. According to some workers the stopper and the chyle stomach are equivalents of proventriculus and ventriculus respectively.

The DIGESTIVE GLANDS are represented by three pairs of *salivary glands*. The saliva from these glands mix with pollens and nectar. The enzymatic action converts the nectar into honey. It is either digested or regurgitated into the comb for future use. Another pair of coiled glands is present in the head of worker bees which produce a nitrogenous food, called 'Royal jelly'.

Respiratory system

The respiratory organs are *tracheae*. The arrangement of tracheae is same as in cockroach and consists of *stigmata*, *longitudinal trunks* and *segmental branches*. In certain regions the tracheae are dilated to become air sacs.

Excretory system

Numerous filiform tubules called *Malpighian tubules* serve as excretory organs. These tubules open into the lumen of the intestine through their proximal end and their distal blind end remains suspended within the haemocoelomic spaces. The excretory products pass out through the alimentary canal.

Circulatory system

Tubular *heart* is present along the mid-dorsal region of the thorax and abdomen. The blood which is pumped by the heart, flows through the haemocoelomic spaces. The blood is known as *haemolymph* and it possesses a few amoeboid cells with prominent nuclei.

Nervous system

The nervous system is well developed in honey bee. These insects possess extremely powerful sense organs and are well known for their power of communication which serves as the basis of their social life. The CENTRAL NERVOUS SYSTEM in honey bee includes (*a*) prominent SUPRA-OESOPHAGEAL GANGLION on the dorsal side of the head which is formed by the fusion of several ganglia, (*b*) SUB-OESOPHAGEAL GANGLION on the ventral side of the oesophagus is formed by the union of three pairs of ganglia and (*c*) a double VENTRAL NERVE CORD, which begins from the sub-oesophageal ganglia and runs along the mid-ventral line up to the posterior end of the abdomen. On each side the supra-oesophageal ganglion is connected with the sub-oesophageal ganglion by a connective. The ventral nerve cord along its path bears three pairs of *thoracic ganglia* and four (in drones and females) or five (in workers) pairs of *abdominal ganglia*. The PERIPHERAL NERVES are given from these different ganglia. From brain, the paired optic nerves arise as broad projections. The important SENSE ORGANS are

antennae and *eyes*. The antennae bear special receptor cells for detecting smell and measuring distances. Both the simple and compound eyes are present. The simple eyes are meant for detecting the intensity of light while the compound eyes are responsible for vision. It has been shown experimentally that honey bees have special power for selection of colours. It can detect a few more colours in the infra-red and ultra-violet zone of the spectrum, which are invisible to the human eye.

Reproductive system

The functional females are known as queens while the males are called drones. The workers are sterile females.

MALE REPRODUCTIVE SYSTEM. In drones, a pair of *testes* is connected with a pair of narrow tubes, each of which is called *vas deferens*. The outer end of the vas deferens dilates into a *seminal vesicle* through which it opens within the *ejaculatory duct*. The *copulatory apparatus* is connected with the terminal end of ejaculatory duct. A pair of prominent *mucous glands* open at the point of union. When matured, the sperms come out of each testis and crowd near the end of the ejaculatory duct. The sperms are transferred to the females in packets, called *spermatophores*.

FEMALE REPRODUCTIVE SYSTEM. In the queen, the paired, tubular *ovaries* are present. In the matured state the ovaries are large and conspicuous. Each ovary contains several tubes and each tube contains eggs at different stages of maturity. Each ovary communicates to an *oviduct* and the two oviducts unite to form a *common oviduct*. The inner end of the common oviduct is connected to a round vesicle called *spermatheca*. The oviduct finally opens to the exterior through a *copulatory pouch*.

MECHANISM OF REPRODUCTION. Each hive contains one matured queen, several drones and innumerable workers. During reproduction, the queen performs a nuptial flight with several drones. The drone which copulates with the female loses its copulatory apparatus and ultimately dies. The sperm cells remain stored in the spermatheca of the female. The queen after returning to the hive starts laying eggs. The fertilization occurs only at this stage. The queen lays both unfertilized and fertilized eggs. The entire process is believed to be either under the voluntary control of the female or by the size of the cell of the hive, where the egg is laid.

Development and Life history

The larvae hatch out of the eggs three days after laying (Fig. 16.78). The unfertilized eggs become drones and the fertilized eggs become either females or workers. The population of male, female and

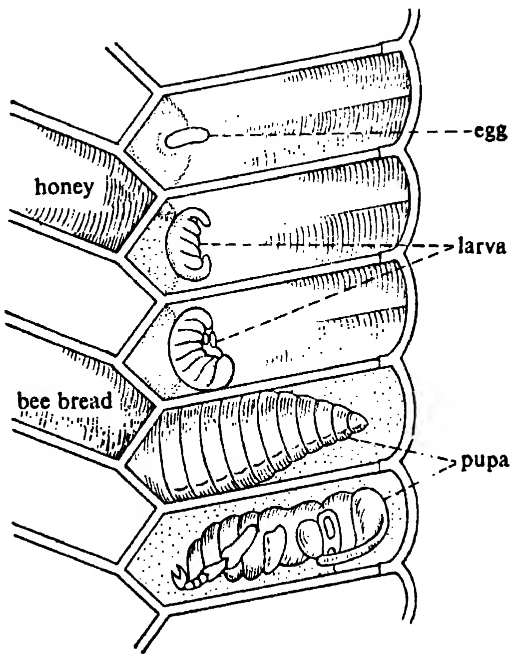


Fig. 16.78. Diagrammatic sectional view of the hive. Note different developmental stages within the cells of the hive.

workers in a hive are controlled by differential feeding of the larvae. The controlling function is done by workers. The future workers are fed with only honey. The would-be drones are given a mixture of honey and pollen grains (called the *bee-bread*) and the future queen is given the special food, 'Royal jelly'. The larva which is selected to become queen, is taken before the third day of development in a special chamber called *queen's chamber*. It is fed continuously for five consecutive days with royal jelly. It results into the enormous increase in size. The larva at this stage produces a cocoon around its body and enters into pupa stage. Inside the cocoon, rapid transformation takes place and finally the adult gets out of the cocoon

by cutting it. If several queens are produced, only one survives and others are eliminated. The queen comes out at the end of fifteenth day, the workers after twenty-one days and the drones after twenty-four days. The worker bees after coming out of the pupal case start working and their duties are changed with the advancement of age. The different works done by a worker bee is given below:

From 1st to 3rd day—it cleans the compartment of the hive where it was born for using them again.

From 4th to 9th day—it works as a nurse and feeds the larvae with its own secretion or by honey produced by others.

From 10th to 11th day—it acts as a builder and constructs new cells in the hive by the wax produced by the wax glands.

From 17th to 19th day—it collects the nectars from the bees which bring it from the outside and converts it into honey. At this time, it also helps to cool the hive by fanning the wing. It also removes debris from the hive to clean it.

From 21st to 25th day—it works as a soldier and protects the hive from the invasion of enemies including the bees from the other hives.

From 25th day onwards—it starts to go out of the hive for collecting nectar and pollen from flowers. It is then known as forager. Life of a worker bee is about six weeks in European countries.

Economic importance

The use of *honey* and *wax* is known to man for a long time. As these two products come from beehive, the honey bees are considered by man as economically important. Bees are very economically important in connection with pollination to agriculturists. The abdominal body hairs and hairs distributed all over the surfaces of their legs are mainly responsible for collecting the pollen grains. The pollen grains are transferred from one flower to other during their honey collection and thus cause pollination. The bees while foraging, collect nectar and pollen from flowers. Within the hive, the worker bees drink the nectar. Inside their honey sac, by the action of special enzyme, the cane sugar part of the nectar is converted into *glucose* (*dextrose*) and *fructose* (*leevulose*). **Constitution of honey:** 454 g of honey contain 165 g fructose (fruit sugar), 142 g glucose, 9 g sucrose, 85 g moisture, 7 g dextrine and gums, 1 g of Fe, Ca, Na and about 4% undetermined substances. The honey thus formed is regurgitated and stored in the hive for future use. The honey is regarded as antiseptic and is believed to have profound medical importance. **Food value of honey:** 454 g of honey is equal to 1·6 kg of potato or 2·0 kg of grapes or 1·4 kg of bananas or 6·0 kg of cauliflower or 2·3 kg of apples. It is also a very powerful tonic and compared to 365 u.g.—Vit. B (Thiamin), 268 u.g.—Vit. C (Riboflavin), 18 mg—Vit. C (Ascorbic acid) or 0·60 mg—Nicotinic acid. The wax is produced by the wax gland of worker bees and is used to construct the hive. Two other products, *propolis* and *balm*, are also collected from various parts of the plants and are used in the construction of hive. The propolis is used as cement to bind broken parts and the balm is taken for polishing inner walls.

Language of honey bee

Bees are known to have some method of communication amongst themselves. As soon as one bee finds a source of nectar, it immediately conveys the source and direction of the source to other bees of the same community. They perform certain rythmic movements and emit odours that are easily received by other bees. When the source is nearer to hive, *reporter bee* performs a *round dance*, turning in a circle, once to left then to right and repeating the same movement for 1½ minute in one place. If the source is further away, the *reporter bee* performs a *tail wagging dance* (Fig. 16.79). It runs towards the direction straight ahead for a short distance, wagging the abdomen, make a 360° turn towards left, run ahead once again and turns right. This is repeated for several times. These dances are closely watched by other bees in the hive and then immediately they come out in search of the source.

Odours play a vital role in their communication. Sudden death of queen bee is relayed to 60,000 or more bees of the hive in less than an hour. Healthy queen secrets an aromatic substance called 'queen substance' which is licked off by her nurse bees, when the queen dies the secretion stops and the absence of the queen substance is

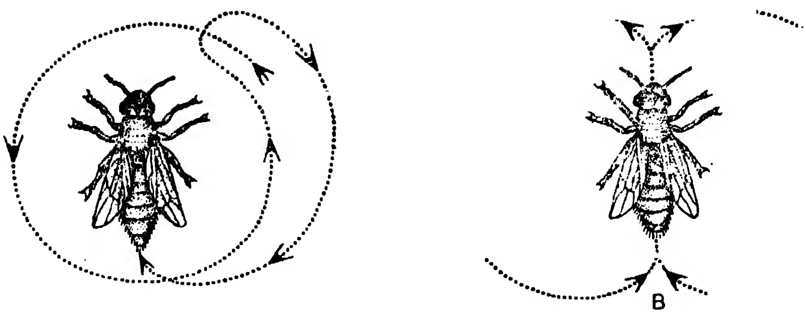


Fig. 16.79. Showing communicating system in honey bee through dancing. A. Round dance. B. Tail wagging dance.

immediately relayed to all the members of the colony. The message being conveyed to all members of the colony they at once set about the vital task of rearing a new queen.

Example of the Phylum Arthropoda—*Silkworm*

The importance of silkworm in silk production was known in China during 3500 B.C. and was later smuggled throughout the world. Silk industry is based on a product released by the silkmoth. The rearing of the silkmoth and production of silk is known as *sericulture*. The silkworm which produces the common silk is scientifically known as *Bombyx mori*. It belongs to the order Lepidoptera under the Class Insecta. Several other forms *Bombyx textor*, *Bombyx fortunatux*, *Bombyx meridionalis* are well known in our country. Certain silks of inferior quality, e.g. Muga, Tussore, etc. are produced from silkworms which are known as *Antheraea assamensis* and *Antheraea mylitta* respectively.

Habit and Habitat

The silk-producing moth *Bombyx mori* is now available in completely domesticated form (Fig. 16.80). The adult moths seldom eat and are primarily concerned with reproduction. Their larvae are voracious eaters. They feed on the leaves of mulberry trees (*Morus indica*, *Morus serrata*, *Morus levigata*). Some moths are single-brooded or *univoltine* and others are many-brooded or *multivoltine*. There is definite life cycle which involves the appearance of stages completely different from the adult. Such transformation is known as complete metamorphosis. The different stages are—*adult*, *egg*, *caterpillar larva*, *pupa* and *imago*.

Adult moth. The adult moths are 25 mm in length and the span of wings is 40–50 mm. The female silk moths are larger than the males. The univoltines are larger than the multivoltines. Usually whitish in colour and in some forms specially the males have grey marks on their wings. The body is distinctly divisible into three tagmata—*head*, *thorax* and *abdomen*. The head contains distinct *eyes* and feathery *antennae*, the later being larger in males. Three pairs of legs and two pairs of wings are present in the thoracic region. Female moths do not have any mouth. They rarely move. Internally, the body contains well-developed excretory and reproductive systems. The digestive system is poorly developed. The excretory organs are three pairs of *Malpighian tubules*. There are three such tubules on each side. A duct from each side unites together to form a common tube which opens into the stomach at its posterior end. In males, the paired *testes* are lodged within a capsule. From each testis originates a duct called *vas deferens* which inflates immediately after its origin to form a *seminal vesicle*. Posteriorly the two vasa deferentia unite to form a much coiled *ejaculatory duct* which opens to the exterior through the genital opening. In the female, each of the paired *ovary* contains four *egg tubes*. From each ovary arises an *oviduct;* the two oviducts unite to form a *common oviduct*. There are *two* female genital apertures—through one opens the oviduct and through the other communicates a large sac-like *copulatory pouch*. A short tube links the pouch with the oviduct. This tube is called *seminal duct*. A portion of it is dilated to act as *spermatheca*.

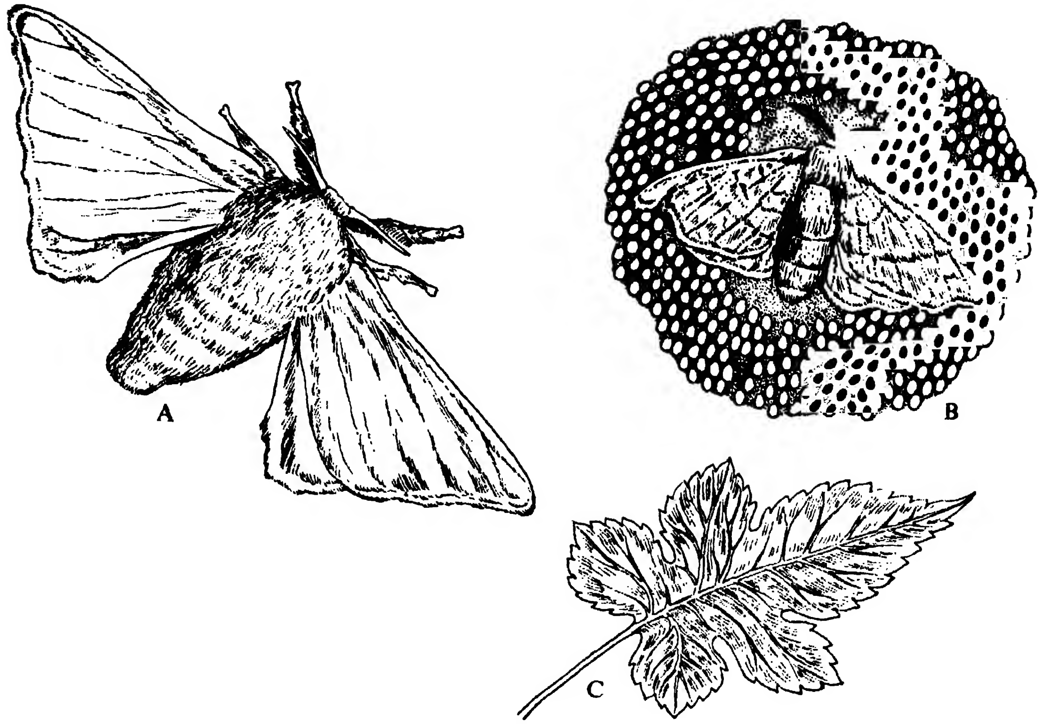


Fig. 16.80. A. Dorsal view of a male silk moth (*Bombyx mori*). B. Female silk moth (*Bombyx mori*) laying eggs. C. A Mulberry leaf—food of the worm. All the three figures are diagrammatic.

Both the sexes are provided with accessory glands which open within the genital ducts. A *scent gland* is present at the terminal end of the female abdominal cavity. Its secretion attracts the males of the same species. During copulation, the male sits on the back of the female and grips it tightly by its chitinous hooks. Such pairing lasts for three hours. This is immediately followed by egg laying. The sperms enter through a small opening on the egg called the *micropyle*. But the actual fusion of male and female pronuclei occurs two hours after laying. *Parthenogenesis*, i.e. development of egg without the participation of sperm, is also common in silk moth.

Eggs. The colouration, size and weight vary in different species. The eggs are small, oval and usually slightly yellowish in colour. The egg contains a good amount of yolk and is covered by a smooth hard chitinous shell. Approximately 500 eggs are laid in 24 hours. In some forms the eggs are glued on the surface of the leaf by a product secreted from a special gland. The univoltine broods hatch after one year but the multivoltine broods come out after 10–12 days. From the egg hatches out a larva called *caterpillar*, which has no resemblance to the adult.

Larva. Each larva is 3 mm in length and is provided with a thick hairy covering (Fig. 16.81A). The colour is usually greyish brown but the colouration changes in course of development. The larva possesses a prominent *head*, distinctly segmented *thorax* and elongated *abdomen*. A conspicuous crescent spot is present on the dorsal side of the sixth segment.

The head is formed by the fusion of three segments. At the anterior end a triangular area is formed by a pair of oval lobes. The mouth parts include a pair of strong *mandibles*, a pair of *lips*, a pair of *maxillae* and two pairs of *maxillary* and *labial palps*. The head also bears a pair of *antennae* and six pairs of *ocelli*. A distinct hook-like structure, the *spinneret*, is present for the extrusion of *silk* from the inner *silk gland*.

Each of the three thoracic segments bears a pair of *legs* having three articulations. The tip of each leg has a recurved hook for locomotion and ingestion of leaves.

The abdomen is divisible into ten segments of which the first nine are clearly marked while the tenth one is indistinct. The third, fourth, fifth, sixth and ninth abdominal segments bear abdominal appendages called *false legs*. Each leg is retractile and more or less cylindrical.

The body of the caterpillar contains following internal structures (Fig. 16.81B):

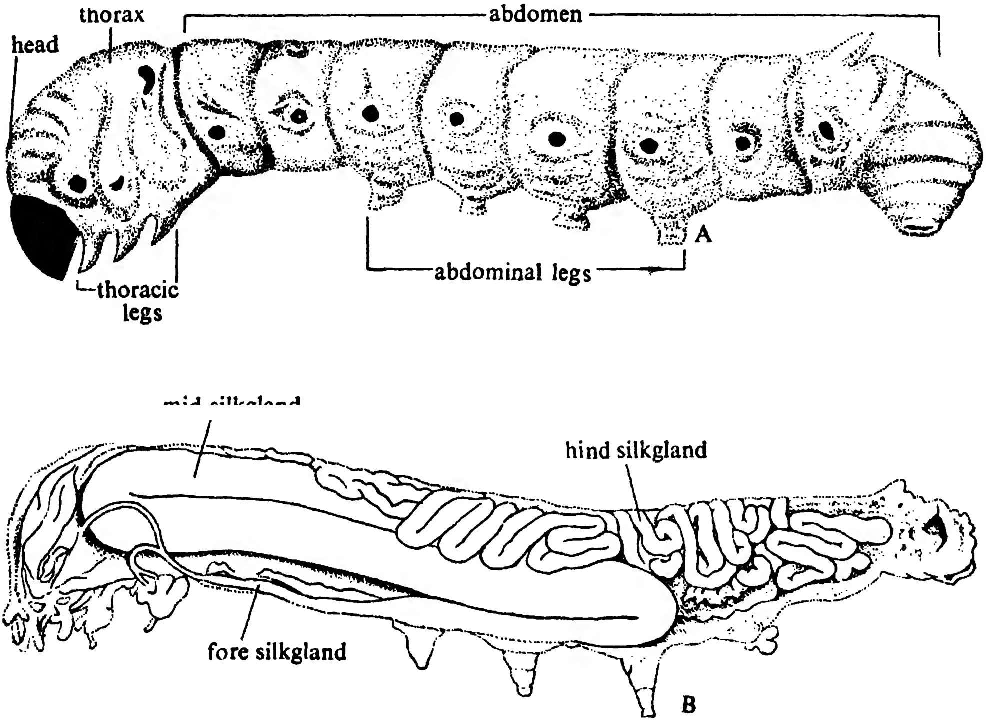


Fig. 16.81. Larva of silkworm moth, *Bombyx mori* (after Chowdhury). A. External features—lateral view. B. General viscera, dissected specially to show the silk gland (lateral view).

(1) Alimentary system. The alimentary canal is prominent and includes a short oesophagus, a spacious stomach, much coiled and long intestine and a swollen rectum. A pair of salivary glands open by a common salivary duct to the mouth cavity and serve as a digestive gland. (2) Respiratory system. Tracheal trunks open to the exterior by nine pairs of spiracle. First pair are present on the first thoracic segment and remaining pairs are situated on the first eight abdominal segments. (3) Circulatory system. The heart is present immediately above the alimentary canal along the mid-dorsal line of the body cavity. It is a transparent contractile tube also known as the dorsal vessel. The blood is usually colourless but may be pink or green. The colour of the silk depends upon the colour of the blood. (4) Nervous system. The nervous system includes a pair of cerebral ganglia as brain and a paired ventral nerve cord carrying twelve ganglia in its path. The sense organs are present as six pairs of ocelli for detecting light and numerous sensory receptors on the maxillary and labial palps.

(5) Silk gland. These unique and conspicuous glands are paired structures, which are present in the fourth to eighth segments of the larva. When fully formed each gland becomes five times the length of the larva and its weight becomes two-fifths of the body weight. Each gland is divisible into three sections—the anterior, middle and posterior (Fig. 16.82). The middle part is broad and called the reservoir. The anterior and posterior parts are pointed at their two ends. The two anterior ends of the glands unite to form a common duct which opens through a spinneret. The posterior part produces a protein called *fibroin* around which the middle part puts an envelope called *sericin*. The silk is released in a liquid state, which soon har-

dens. A pair of accessory glands called the glands of filippi or Lyononet's glands open into the duct of the silk gland. The secretion of this gland mixes with that of the silk gland

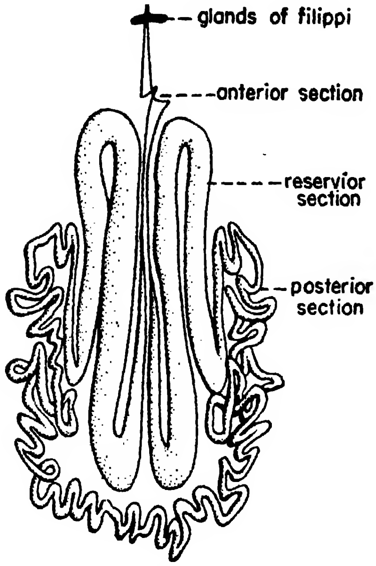


Fig. 16.82. Silk gland of *Bombyx mori*.

and probably lubricates the inner and outer cores of the silk. (6) Reproductive system. The reproductive organs are very minute and their ducts are indistinct.

Transformation of larva. The larva is a voracious eater. In the beginning, chopped young mulberry leaves are given as food, but with the advancement of age entire and matured leaves are provided as food. The routine of caterpillar includes only two activities—eating and sleeping. It grows fantastically and increases, 10,000 times in weight from newly hatched state. Such growth involves the consumption of mulberry leaves which are 30,000 times more than its body weight. The growth requires the replacement of exoskeletal covering and the larva within its 30–40 days life does the same for four times. Such removal of the old exoskeleton is known as moulting. At the time of moulting, the larva does not take any food and places its head upwards. This phase is very critical in the life of larva. At the end of fourth moult a fully formed larva with matured silk gland becomes transparent and golden brown in appearance. At this stage the larva ceases to eat and starts spinning silk around its body from outside to inside (Fig. 16.83). In order to make a

Fig. 16.83. Cocoon formation by the larva of silkworm moth. 1–4. Different stages of cocoon formation. 5. Fully formed cocoon. 6. One half of the cocoon is removed to show the position of the pupa. Entire cocoon is formed by a single thread of silk and silk is obtained by unreeling the thread.

complete covering the larva rotates 60,000 to 300,000 times and the silk is liberated at the rate of 15 cm per minute. This covering, called the cocoon, is formed of a continuous silken thread of 400–1500 meters long. The caterpillar takes 3–4 days to complete a cocoon within which the larva, now known as pupa, remains completely immobile. A cocoon may be of varied shapes and colours. The cocoon formed by a male moth is lighter in colour than that of a female and contains more silk.

Pupa. It is covered by a hard shell. It generally remains immobile, but can change its position by the contractile movement of the last few abdominal segments. Within the pupa, considerable activity takes place. The old structures of pupa are broken down by a process called histolysis and new parts of the adult are produced. Gradually within the cocoon, pupa transforms into a stage called imago. For the purpose of breaking the cocoon, the imago liberates a fluid which dissolves the covering at one end. The emergence of adult takes place after 10 days of pupal life (Fig. 16.84).

Factors influencing the life cycle. The life cycle of silkworm is influenced by physical factors like temperature, light and humidity. These factors in one hand control the growth of the worm and at the same time determines the quality of the silk. The univoltines are more susceptible to temperature changes than the multivoltine forms.

Extraction of silk. The continuous silken thread which builds the cocoon serves as the source of the silk of our requirement. As the adult emerges from the pupa, the continuity of this thread is torn. For this reason, a few selected cocoons are retained to serve as 'seed' to maintain the population and the rest is destroyed for the extraction of the silk. Usually the male cocoons are selected from their sex-linked skin markings for getting more silks. For the purpose of extraction, the cocoons which are ten days old are immersed in hot water. Such treatment kills the inner pupa. The killing is also done by steaming or dry heat or fumigation. The killing is followed by assortment of cocoons on the basis of their colour and texture. The treatment of heat for killing also removes the binding material or gums of the silk fibres. Then the thread is skilfully unreeled. Threads drawn from several

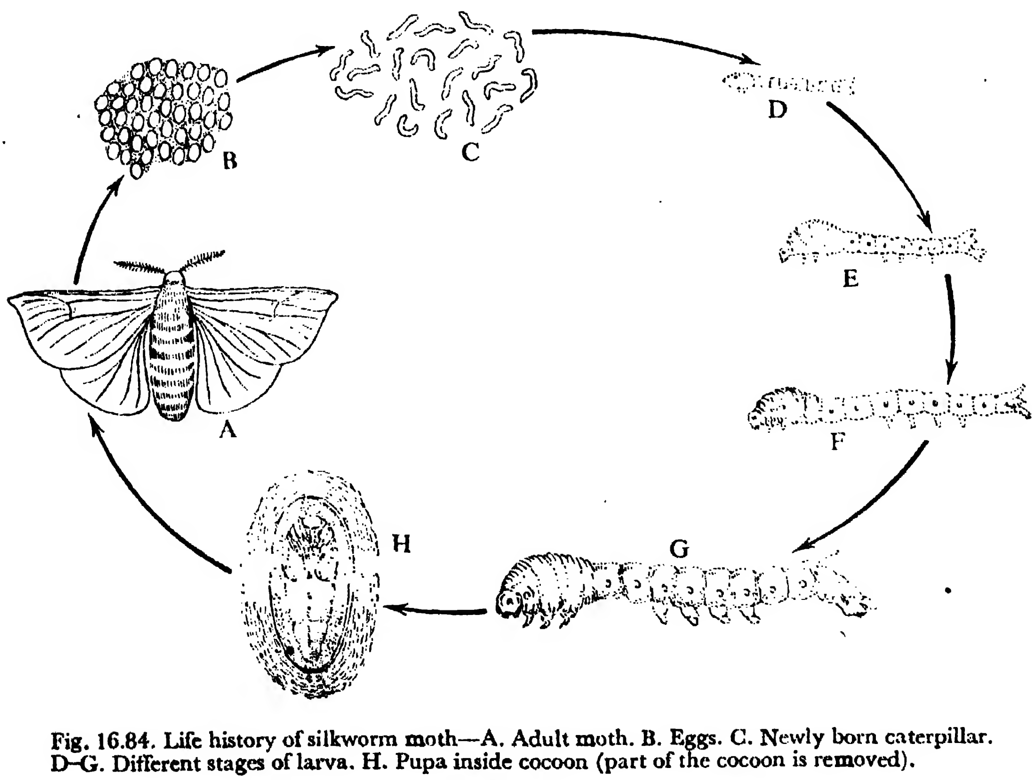


Fig. 16.84. Life history of silkworm moth—A. Adult moth. B. Eggs. C. Newly born caterpillar. D–G. Different stages of larva. H. Pupa inside cocoon (part of the cocoon is removed).

cocoons form the raw silk. Such silk is then treated variously to make it ready for spinning. Nearly 25,000 cocoons are required to get a pound of silk and the annual production of silk throughout the world is nearly 50 million pounds.

Composition of silk. Silk is the secretory product of silk gland. The silk thread is composed of proteins. It has an inner core of *fibroin* ($C_{30}H_{46}N_{10}O_{12}$) and an outer enveloping layer of *sericin* ($C_{30}H_{40}N_{10}O_{16}$). The silk is secreted as a liquid which becomes hard immediately upon being extruded. The colour of sericin corresponds with that of the blood, whereas the fibroin is always white. The silk thread consists of 75–80% of fibroin and 20–25% of sericin.

Modern sericulture. There are certain measures which are followed to improve the cultivation of silk worm to obtain good quality silk.

(i) Cultivation of food plants for silk-moth larvae (*a*) plantation, (*b*) regular prunning.

(ii) Maintaining of proper stock of silk moth.

(iii) Rearing of eggs, larvae and cocoons.

(iv) Precaution against diseases attacking at different stages of life cycle.

(v) Extraction of silk.

(vi) Economy involved in this industry.

Sericulture can be grouped in two major heads

(i) Mulberry silk culture—Pure silk.

(ii) Non-mulberry silk culture—Endi, Muga, Tussar, etc.

Problems of sericulture. Silk industry requires silk as well as new generation of worms. It involves in one hand modern techniques for extracting and processing silk and on the other hand better methods for rearing silk moths. In countries like Japan and Italy significant researches have been carried out to improve the genetic

TABLE 3—ARTHROPODA

Names of the different stock, food plants and their place of availability in India

	NAME OF INSECT	FOOD PLANTS	CULTURE	PRODUCTION AREA
A. Mulberry silk	*Bombyx mori* L.	(Mulberry plants) *Morus allu*	Silk culture	Kashmir, Mysore W. Bengal (Bankura, Murshidabad and Malda)
	(*i*) *Philosamia cynthia*	(Castor plants) *Ricinus communis*	Sericulture	Assam, W. Bengal (Malda, Bankura)
B. Non-mulberry silk	(*ii*) *Antheraea assama*	(Saalu) *Litsaea polyantha* (Chapa) *Michelia oblonga*	Muga culture	Assam, Mysore, W. Bengal, (Murshidabád, Bankura)
	(*iii*) *Antheraea paphia* and *Antheraea mylitta*	(Arjuna) *Terminalia arjuna*, (Sal) *Shorea robusta*, (Phutuka) *Melastoma malabathricum*	Tussar culture	Madhya Pradesh, Assam, W. Bengal (Bankura, Malda)

qualities of the silkworm for yielding better silk at a low cost. This profitable industry is often menaced by various diseases resulted from the infections of virus, fungus, bacteria and protozoa. The table 4—Arthropoda shows the particulars of some common diseases and their remedies.

TABLE 4—ARTHROPODA

Common Diseases of Silk Worm and their Controlling Methods

NAME OF THE DISEASES	NATURE OF THE DISEASES	SYMPTOMS	CONTROLLING METHODS
Muscardine	Fungal, produces various colour markings along the skin.	Worm becomes hard.	Maintenance of stocks which are resistant to the disease.
Pebrine	Protozoan (*Nosema*), transmitted through egg.	Undernourished larvae atrophy. Production of lesser and defective silk. Death of embryo.	Treatment of eggs with warm water (47°C).
Flacherie	Bacterial.	Physical disability and softening of the skin.	Careful rearing of improved stocks in healthy condition.
Grassarie	Viral.	Affects moulting. Skin becomes yellow and blood turns into milky in appearance.	General cleanliness and separation of affected worms.

EXAMPLE OF THE PHYLUM ARTHROPODA—*HOUSE-FLY*

Usually, the insects considered injurious are those which bite or sting. The house-fly can neither bite nor sting, yet it is considered as one of the most notorious of all the harmful insects. These flies endanger human lives by carrying germs of various diseases. The common house-flies of our country are *Musca vicinia* and *Musca nebalia*. One, which is described here is scientifically known as *Musca domestica* and it is also common in Europe.

Habit and Habitat

The house-flies are daytime visitors of human habitations specially with non-hygienic conditions. The open drains, garbages, kitchen and pantries are the favourite residing and breeding places of the house-fly. The house-flies have special fascination for sitting on hanging or stretched ropes and wires. At night innumerable flies are seen to be sitting on such ropes and wires. The house-fly, being smart and agile, gives frequent flying visits to other parts of the house and sits over uncovered foods. Such visits bring various germs with its body and contaminate human foods.

External structures

The grey coloured body has yellowish tinge on the ventral side. The dorasl side of the thorax has four elongated lines (Fig. 16.85). The abdomen possesses a single streak on the mid-dorasl line. As in other insects, the body of house-fly consists of three tagmata—*head, thorax* and *abdomen*.

HEAD. The head of the house-fly is small and semicircular in outline. A pair of much

prominent compound eyes each containing nearly 4000 ommatidia and three small simple eyes or ocelli are present. The appendages include the ANTENNAE and MOUTH PARTS. The antennae are paired, short and flexible. The distal segment of the antenna is the largest one which contains a brush-like *arista*. The mouth parts are well developed and facilitate in its peculiar way of feeding. The type of mouth parts found in this animal is called *spongin type* which contains two portions—(*a*) *proboscis* and (*b*) *food channel*. The proboscis, formed by the fleshy and retractile labium, may be separated into three parts—(*i*) *basiproboscis* or *rostrum*, (*ii*) *mediproboscis* or *haustellum* and (*iii*) *distioproboscis* or *labellum*. The rostrum carries in front a pair of maxillary palps. The middle part is movable and powerful. The last part is extended as a pair of membranous oval and spongy *oral lobes* or *labella*, which is traversed by numerous channels called *pseudotracheae*, opening externally along the margin. All these pseudotracheae open distally in a single aperture, called the mouth. The mouth is situated at the tip of the next part known as food channel. The food channel is formed by the participation of labrum, epipharynx and hypopharynx. The notable feature in the mouth parts of house-fly is the absence of mandible, the function of which is taken up by rows of teeth like serrations in the undersurface of oral lobes.

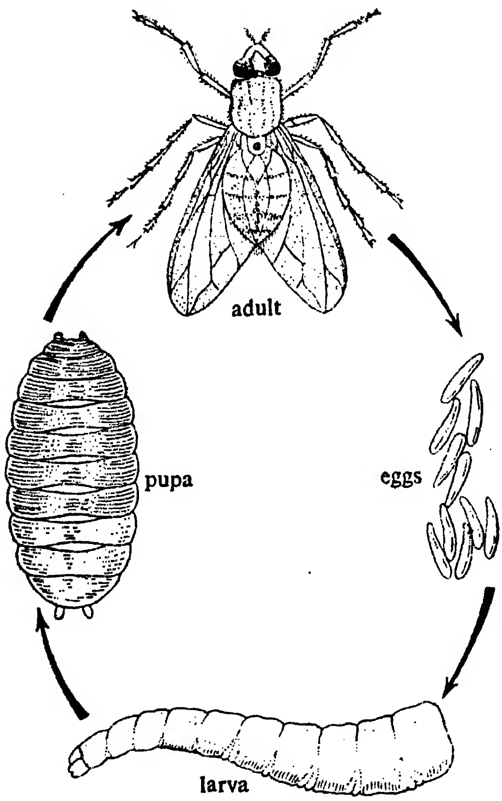


Fig. 16.85. Life history of house-fly.

THORAX. Three segments are not clearly demarcated in this tagma, which bear three pairs of legs and two pairs of wings. Three pairs of walking legs have typical insect-like divisions. The terminal end of each leg is provided with a pair of curved claws. In between the curved claws lie a pair of glandular pads called *pulvillae* having numerous hollow hairs. Through these hairs a sticky substance comes out which helps in walking. Numerous hairs and bristles occur throughout the surface of the legs. There are specialised sense organs in the tarsus of each leg. When these tarsi come in contact with sweet water the proboscis protrudes out. Of the two pairs of wings, only the anterior pair is prominent, broad, transparent, hairy and triangular. The posterior pair is modified into stick like *halters* which work as sensory and balancing organs. When at rest the wings fully cover the abdomen and during flight they vibrate rapidly to produce a typical sound. In the adult males, the ability to fly lasts only for 2 weeks.

ABDOMEN. It is oval, hairy and segmented. In females there are nine segments but the males have eight. In the females, four segments from the 7th to 10th participate in the formation of retractile ovipositors for laying eggs. In males, the last four segments form a genital pouch and other associated structures.

Inner structures

The muscular system specially, the flight muscles, are well developed. The flight muscles constitute the 11% of its body weight. The alimentary canal is long and carries distinct diverticulum and crop. The crop is believed to have sucking ability. The respiratory system is represented by 10 pairs of spiracles, longitudinal tracheal trunks and their segmental branches. A pair of large dilated base in the abdomen is known as aerostats. Of the ten pairs of spiracles, the eight pairs

of abdominal spiracles are simple in construction. The two pairs of thoracic spiracles are specially modified and are supposed to act as sound producing organs. The network of tracheae has reduced the haemocoelomic space. Such spaces are confined near the wing muscles and are filled up with blood containing carbohydrates and other reserve fuels. The function of excretion is carried out by four elongated Malpighian tubules. The fusion of thoracic segments has led to the condensation of nerve cord.

Mechanism of feeding. It ingests liquid food. The solid foods like sugar are moistened by its saliva and are taken in a dissolved state. During ingestion the fly extends the proboscis and immerses the labella within the food. The pseudotracheae of the labella are filled up with the liquid food by capillary action. The sucking action of muscular pharynx draws the food inside the food channel. The crop is filled up with large volume of food, which enters to the mid gut slowly.

Life history

Copulation continues for a couple of minutes. The male grasps the dorsal side of the female with the help of pro- and mesothoracic legs. The female fly inserts its ovipositor within the genital atrium of the male.

A week after copulation the female fly starts laying eggs. After one copulation, eggs are laid in 5 or 6 batches, each consisting of 100-200 eggs. For the laying of egg it requires a medium containing sugar, protein and water. With the help of its ovipositor the female fly digs organic manures, debris, decaying fruits and vegetables. The white eggs are elongated and have curved dorsal thickening. The eggs hatch within 8-24 hours and a larva called the *maggot* or *gentle* comes out of the egg by making an elongated slit on the dorsal side. Sometimes the hatching is completed immediately after the laying of egg. The maggot is white and 2 mm in length. Its anterior end is narrower than the posterior end. There is no sign of head, legs and wings in the maggot. The body is divisible into thirteen segments, of which the anterior segment is rudimentary and contains two *oral lobes*. Each oral lobe has two sensory *tubercles* and a number of branched food channels. The mouth is placed between the two oral lobes. On the anterior end of the mouth, there is a hook-like mandibular *sclerite* which also helps in locomotion. Each segment from sixth to twelfth, possesses semilunar spiny structures called *seminiferous pads* on its ventral side. These are structures for locomotion. On the mid-dorsal position of the twelfth segment, a pair of D-shaped spiracles communicates with the inner tracheal trunk. In course of its rapid growth, the larva moults twice and a pair of fan-shaped spiracles develop on the dorsal side of the third segment. The maggot after its full growth contracts and enters into the stage of *pupa*. A hard case is formed around the body from which only the spiracles remain projected outwards. Inside the covering rapid change takes place. Except the nervous system all the larval structures are broken down by a process called histolysis. New structures are formed from special groups of cell called *imaginal discs*. When fully formed the young fly forces open a lid at the anterior end of the pupal case and comes out. The newly emerged fly is colourless and with rudimentary wings and short legs. But within a short period, swelling and elongation of different parts occur. Thus the individual becomes transformed into an adult.

Control of flies

The house-flies endanger human life by contaminating foods and drinks with germs of various diseases. These germs come along with its body and also with the excreta and regurgitated products of the flies. All preventive measures adopted against the house-fly are two-fold--against the adult fly and against the larvae and maggot.

(*i*) *Against adult flies*. The flies prefer filthy places, thus it is necessary to maintain general cleanliness in and around the houses. The uses of insecticides specially the use of poisonous threads help to reduce the number of flies. But most important is to keep all the foods and drinks under cover so that the flies may not sit over it.

(*ii*) *Against larvae and maggot*. The flies can only be erradicated properly by taking measures against its larvae and maggot. The favourite breeding places of the fly should be cleaned and treated with insecticides. It must be remembered that the

measure which is adopted against adult fly can produce more significant result if taken against its breeding places.

Example of the Phylum Arthropoda— *MOSQUITO*

The mosquitoes are probably the most notorious insect, which not only act as carriers or vectors of various diseases but also are extremely disturbing specially during sleep. Following types of mosquitoes are well known: (A) *Anopheles* sp.—vector of parasites causing malaria. (B) *Culex* sp.—vector of parasites causing malaria in birds and filariasis in man. (C) *Stegomyia* sp.—responsible for carrying germs of yellow fever. (D) *Aedes* sp.—causes a fever called *Dengue*.

Habit and Habitat

Mosquitoes live in swarms and prefer to stay in tropical damp areas. These insects are said to be nocturnal but are also found to be active in daytime. It shows preference to dark colour. The male mosquitoes are vegetarian and live upon plant saps. It is the females which are sanguinivorous and suck blood from most land-living vertebrates including man. Any source of stagnant water serves as their breeding place and life cycle includes larval stage which are totally dissimilar from the adult. Thus the metamorphosis is complete.

External structures

These small sized insects have the body divided into head, thorax and abdomen. A short neck connects the head with the thorax.

Head. The head is small and more or less round. It contains following structures: (*i*) a pair of prominent bean-shaped compound eyes, (*ii*) in front of compound eyes a single triangular lobe called *clypeus* is present. It carries a pair of elongated *antennae*, one on each side of the head. The antennae are bushy in males. (*iii*) The mouth is provided with appendages called mouth parts or trophi. (Fig. 16.86). The mouth parts in males are for sucking but in females these are adapted for piercing and sucking. The different appendages form a structure called *proboscis*. The proboscis is well developed in females. It consists of—(*a*) one pair of needle-like *mandibles* having sharp tips, (*b*) one pair of needle-like *first maxillae* with sharp serrated tips. Each first maxilla carries a segmented maxillary palp on the outer side of the proboscis. The maxillary palps are longer in males than females, (*c*) one pair of *second maxillae* are united to form *labium*. A groove is present on its upper side and its terminal end bears the white leaf-like lobes called *labellae* having numerous sensory hairs at the free end. (*d*) The *labrum* and *epipharynx* are fused to form a single structure with free sharp end. A groove is present on its lower surface. (*e*) A chitinous blade-like *hypopharynx* with pointed tip, bears the opening of salivary gland at its base.

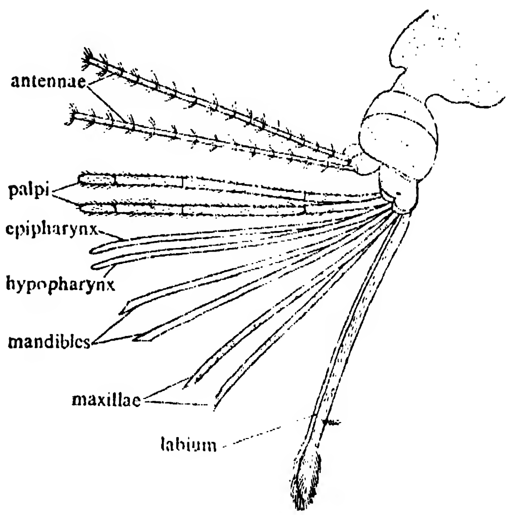


Fig. 16.86. Head of a female mosquito (diagrammatic and much enlarged). Mouth parts are separated to show the details.

The hypopharynx and epipharynx unite to form a tube through which blood is sucked. Labellae of the labium rest over the skin, the mandibles cut the skin and first maxillae, epipharynx and hypopharynx enter within the skin. In males, mandibles are absent and hypopharynx is fused with the labium.

Thorax. It consists of one large (mesothorax) and two small segments (prothorax and metathorax). The thorax carries one pair of wings and three pairs of walking legs, one pair in each segment. The legs are built up in typical insect pattern, but tarsus is long and coxa is short in each leg. The wings are borne on the mesothoracic segment (second thoracic segment) and are effectively used in flying. They are

spotted in *Anopheles*. Second pair of wings are extremely small, ill-developed and modified as the *halters* and these are used as balancing and sensory structures. In *Culex*, the wings beat at the rate of 278–307 per second. The lateral side of the thorax carries *stigmata*.

ABDOMEN. Abdomen is long and narrow. It is covered by scales which are arranged in an imbricate fashion. Only the females contain abdominal appendages in the form of pair of knob-like *ovipositor*. The eighth segment carries anal opening. Reproductive opening is present on the ninth segment.

Inner structures

The ALIMENTARY CANAL (Fig. 16.87) consists of (*a*) MOUTH. This contains several appendages and it leads to the pharynx; (*b*) PHARYNX. It works as a pumping organ to suck the fluid; (*c*) OESOPHAGUS. It is a narrow straight tube with three reservoirs or diverticula. Two *anterior oesophageal diverticula* and one large *posterior oesophageal diverticulum* are present at the anterior and at the posterior ends respectively. The oesophagus leads to the stomach and the opening is guarded by an oesophageal valve, (*d*) MID GUT OR STOMACH. It is a straight tube running up to hind gut. In between mid gut and oesophagus thick-walled *Proventriculus* is present. Near the junction of mid and hind gut, numerous thread-like *Malpighian tubules* open; (*e*) HIND GUT OR INTESTINE runs straight up to the anus. Two sets of *salivary glands*, each with three lobes, are the DIGESTIVE GLANDS of mosquito. These are placed below the alimentary canal and remain in the thoracic region.

The alimentary canal is adapted for taking a heavy meal. The saliva, produced by salivary glands, contains enzymes which prevent coagulation of blood. The blood is sucked by the pumping of pharyngeal wall and after mixing with saliva is stored in the oesophageal reservoirs. It then passes through the stomach and intestine.

The heart of *Anopheles* is muscular but non-neurogenic. In the heart of *Culex* posterior ostia are present and its blood contains four types of proteins. In comparison to its size the eyes are quite large. In *Culex*, each facet of the eye measures up to 16 μm. Another feature also observed in *Culex* is the relationship of rhabdomes and retinular cells. Here the rhabdomes are attached with the cytoplasm of retinular cells only at the proximal end. The sensory structures are well developed. The adult mosquitoes can discriminate distilled water and NaCl solution by tarsal chemoreceptors. The feeling of warmth is an important factor in finding out the host.

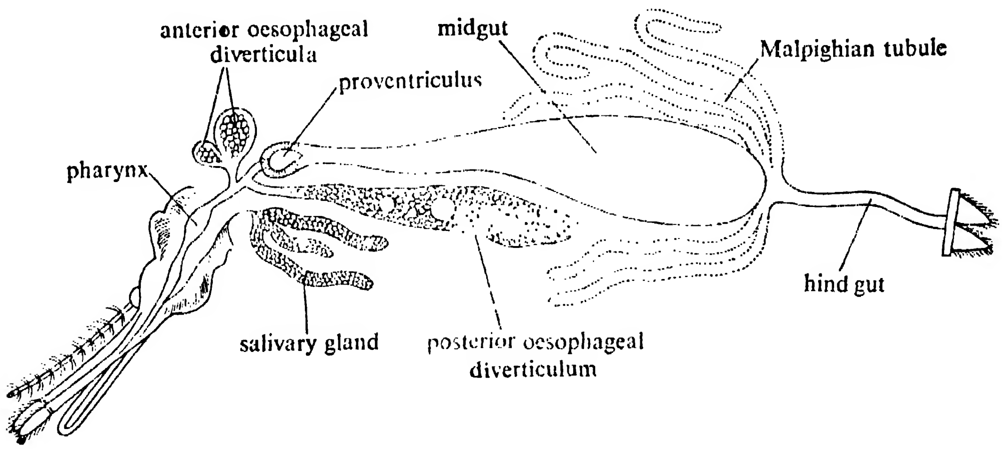


Fig. 16.87. Alimentary system and associated structures of a mosquito.

Life history

Fertilization is internal. Mating takes place during flight. The sound produced by a female mosquito attracts the flying males. After mating the female mosquito selects some stagnant water of low depth for laying eggs. The eggs float

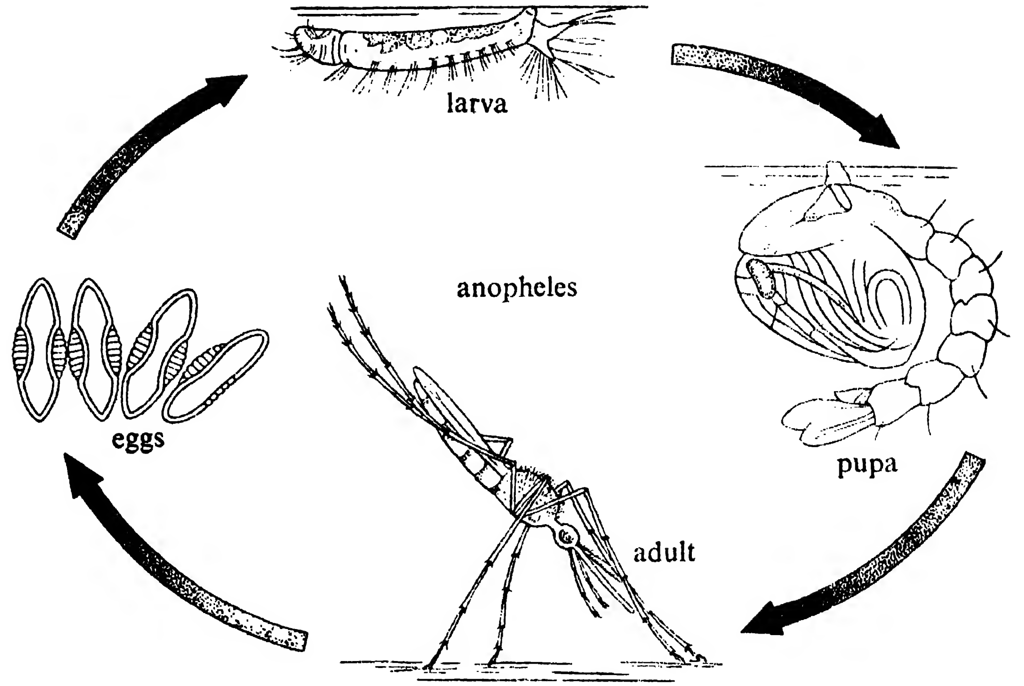


Fig. 16.88. Life history of *Anopheles* mosquito.

in water. *Anopheles* eggs remain scattered and are provided with lateral air-floats (Fig. 16.88), the *Culex* eggs are arranged to form a raft (Fig. 16.89) by the movement of the hind legs of the female. These eggs remain attached with the raft by means of the surface tension of water. At the posterior end of each egg a water droplet condenses which is gradually absorbed in course of development. The

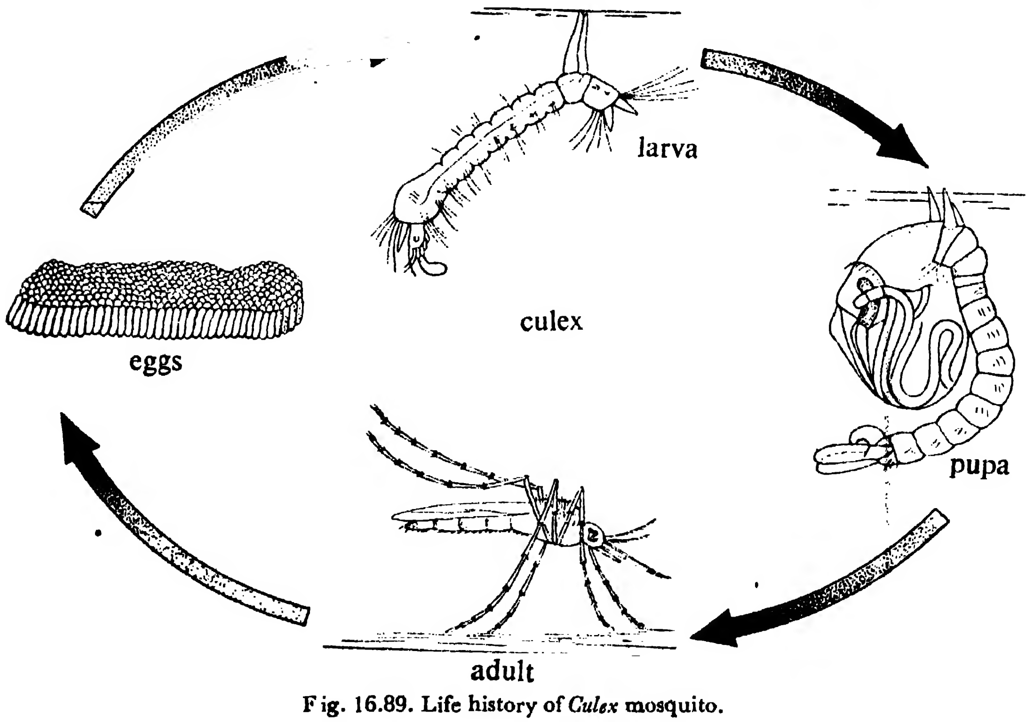


Fig. 16.89. Life history of *Culex* mosquito.

larva which comes out of the egg is aquatic and its body is divisible into three parts—*head*, *thorax* and *abdomen*. The head possesses a pair of lateral compound eyes and an opening called mouth. The mouth parts are represented by a pair of *maxillae*, a pair of *mandibles* and a bunch of hair-like feeding brushes. The larva eats algae and micro-organisms. The thorax is the broadest part and contains tuft of hairs. The abdomen consists of nine segments and has bundles of lateral hairs and a long and pointed siphon. The siphon contains air-tubes each of which has two spiracles and terminal flaps at the outer end. The secretion of a gland called *peri-spiracular gland*, around the spiracle, helps the larva to float on the surface of the water. The air-tubes are in connection with the inner branched network. The anal segment bears tracheal gills which carry on aquatic respiration. The anal papillae in larva constantly absorb water which is again eliminated as urine. The larval integument plays an important role in aquatic respiration. The larva of *Anopheles* floats parallel to the surface of the water, but the *Culex* larva remains under water and only the terminal end of the siphon peeps through the surface of the water. The ascent of larva depends upon the lack of oxygen and not on excess carbon dioxide. In course of development, the larva transforms into *pupa*. The pupa is mobile but it does not eat anything. The anterior part is broad and called the cephalothorax. The narrow abdomen contains nine segments. A pair of large fins on the eighth segment work as organs of swimming. The dorsal side of the thorax bears a pair of small respiratory trumpets, the openings of which are guarded by numerous hairs.

TABLE 5—ARTHROPODA

Comparison between *ANOPHELES* and *CULEX*

Features	Anopheles	Culex
1. Eggs	Laid singly and scatteredly. Each egg is narrower at both ends and is provided with lateral air-float which helps in floatation.	Laid in clusters and are arranged to form a raft. Eggs are cigar-shaped and are devoid of air-float.
2. Larva	Lies parallel to the surface of water.	Hangs perpendicularly downwards in water and only the terminal end of the siphon peeps through the surface of water.
3. Pupa	Possesses a short respiratory trumpet.	Possesses a long respiratory trumpet.
4. Adult	At rest, the body makes an angle of 45° with the surface. Wings are usually spotted. Abdomen is usually without scales. Maxillary palps in both the sexes are almost equal in length to the proboscis. The last segment of the maxillary palp is club-shaped.	At rest, the body lies parallel to the surface. Wings are not spotted. Abdomen bears scales. Maxillary palps are equal in length to the proboscis in male, but in females these are slightly smaller than proboscis. The last segment of the maxillary palp is not club-shaped.
5. Carrier of parasite	Females act as carrier of malarial parasites in man.	Females act as carrier of malarial parasite in birds and filarial worms in man.

Within the pupa rapid transformation takes place; only a few cells produce the adult structure by using up most of the pupal material. The full-grown mosquito comes out by breaking the pupal skin along the dorsal side. Immediately after coming out of the pupal case, the mosquito rests on the floating shell for a while to dry up and then takes off into the air.

The biological organisation of different mosquitoes is basically similar. The differences between *Anopheles* and *Culex*, two very common genera of mosquitoes, are shown in Table 5—Arthropoda.

Control of mosquito. By transmitting various diseases, the mosquitoes not only endanger human lives but also incapacitate millions of working hands. Therefore, all necessary measures should be taken against them. Following preventive measures are usually adopted.

1. Mosquito needs stagnant water (even a little collection of water on the surface of leaf is enough) for breeding. Thus measures should be taken to clear all such sites where water-logging takes place.

2. Spray of kerosene, detergents and insecticides in the breeding areas serve the purpose.

3. Effective biological control can be done by introducing larvae-eating fishes.

4. Mosquito-nets and curtains should be used to prevent the bite of mosquito.

SOME IMPORTANT INSECTS

SILVER FISH

These insects, *Lepisma saccharina* (Fig. 16.90A) are commonly seen in cupboards and book-racks, where they devour starchy products. The body is small, flat and silver-coloured. The mouth parts are adapted for chewing. The compound eyes are insignificant. In the exoskeletal covering, the ventral sternites are not covered by dorsal tergites. The thorax is distinct and the prothorax forms the largest segment of the body. The abdomen has ten segments. The eighth and ninth segments bear small appendages. The last abdominal segment carries at the posterior end a pair of long, many-jointed cerci and a long tail in between. The entire body is covered by shining scales. The excrement products are in the form of dry pellets. The heart hangs from the dorsal body wall by means of threads. The adults can moult and possess regenerating power.

SPRINGTAIL

These are small, soft and wingless insects (Fig. 16.90B), which live under fallen leaves, decaying vegetation and beneath the piles of logs and woods. The well-known genera are *Bourletiella*, *Isotonia* and *Nearura*. Each antenna is made up of 4–6 segments and the antennae are responsible for perceiving warmth. These insects prefer moist places and such moist conditions are sought by determining the humidity of both ground and air. The compound eyes are absent but eight identical simple eyes are present on each side. The mouth parts are mostly of chewing type. The abdomen has six segments and is provided at the terminal end with *anal fork* or *furcula.* This furcula remains engaged in the ventral side of the fourth abdominal segment, called *hemmule*. When the furcula attempts to extend, it slips out from the catch of the abdominal segment and throws the insect into the air. Luminiscent organs are seen in many and fat body serves as the source of light. Malpighian tubules are absent and its excretory function is carried by special glands which open above the base of the labium through a common duct. The fat body contains a special kind of cells called *urate cells* which collect uric acid crystals. The males release hundreds of spermatophores. Each spermatophore remains attached on the surface by a thin hyaline stalk. When these spermatophores get in touch with the moist vulva of the female they burst open to release the sperms. Some sperms enter within the body through the female genital opening and fertilize the eggs. A pit in the anterior dorsal region of the embryo contains a peculiar filamentous dorsal organ which always absorbs water.

LOCUST

The term locust includes gregarious and migratory grasshopper-like forms. Large head with prominent eyes is curved downwards and incompletely concealed by prothorax. Each lateral side of the first abdominal segment carries a tympanum. In females, the ovipositor is made up of small plates. Some common species of locusts are: *Locusta migratoria*, *Schistocerca gregaria*, *Pachytylus cinerascens.* The locusts

have two phases in their life—*solitary* and *migratory* (Fig. 16.90 C & D). The migratory phase appears due to some unknown reason and just before migration the population increases rapidly. The swarms move like a cloud and the direction is guided by the flow of wind. The swarms of locusts damage plant population severely in course of their journey. The swarming does not occur each year. The wingless young locusts also migrate by hopping. Usually they moult five times.

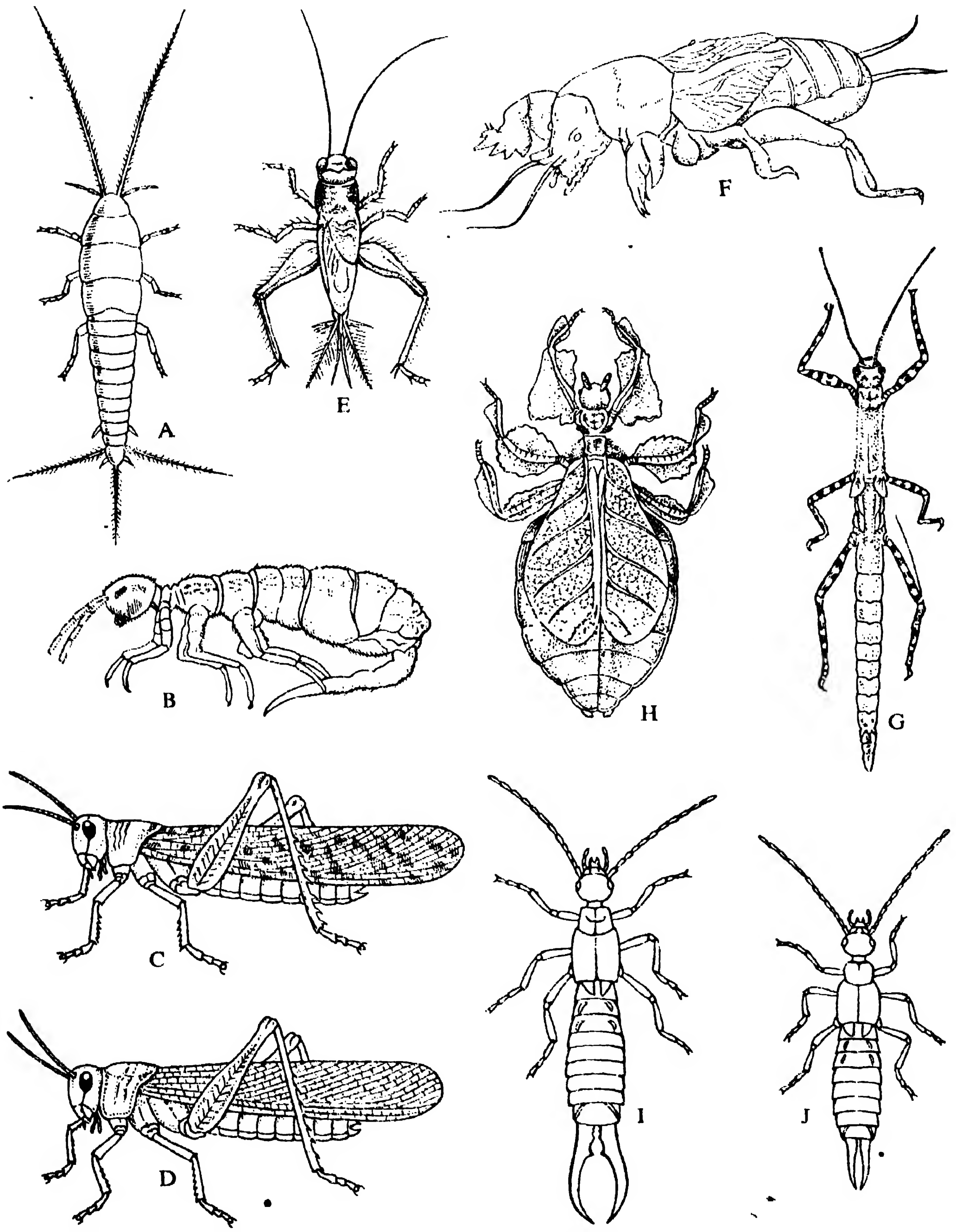


Fig. 16.90. Some important insects—A. Silver fish (*Lepisma saccharina*). B. Springtail. C. Swarming locust. D. Solitary locust. E. House cricket (*Acheta domesticus*). F. Mole cricket (*Gryllotalpa gryllotalpa*). B. Stick insect (*Diapheromera femorata*). H. Leaf insect (*Phyllium scythe*). I. Male Earwig. J. Female Earwig (*Forficula auricularia*).

At the end of fourth moult the instar is sexually active but the fertility is reached only after the fifth moult.

RICE BUG

The rice bug (*Leptocorisa varicornis*), commonly known as Gundhi bug, is a Hemipteran insect causing serious damage to paddy crop. It has a typical hemipteran body plan with sucking type of mouth parts. This insect emits an unpleasant odour from the abdominal scent gland, so the name Gundhi bug for the insect. The milk stage of the paddy grain is its main target. The rice bug sucks out the milky juice and leaves only the white chaffy husks. In case of severe infection all the paddy grains become chaffy.

The pest breed amidst wild grasses in uncultivated areas near paddy fields. When the rice is advancing in milk-grain stage, the adult insects invest the cultivated areas. An adult insect has a slender body with a length of about 15 mm. The anterior pair of the wings is tough and thick while the posterior pair is membranous in nature. The insect is greenish in young stage which turns into a mixture of green and brown in adult which finally turns into brown in old stage.

Females lay small blackish-brown bead-like eggs. The rounded eggs remain arranged in linear fashion on the ventral surface near the midrib of leaf blades of the host plants. The eggs require about a week's time to hatch. The resultant nymphs, immediately after emergence, start sucking the plant juice and develop into adults within two to three weeks' time.

Control measures

Routinewise schedule as preventive measures:

(i) Selection of paddy-growing areas free from wild grasses which are the host plants on which the rice bug inhabits.

(ii) To clear off paddy stubbles by ploughing or by burning and scrapping of bunds as a regular routine.

(iii) Step up of light traps can be used in field with contact insecticide near paddy field to attract adult pest during milky stage of paddy grain.

(iv) Regular check-up of egg masses on paddy field and immediate step is advisable if egg masses are noticed.

Chemical measures:

(i) Contact insecticide—5% BHC spray or dust on crops and bunds.

(ii) Paddy field is to be flooded with water and then insecticide along with oil emulsion is to be applied. Nicotine sulphate, lubricating oil emulsion, kerosine emulsion or lime sulphur solution are generally used.

CRICKET. These solitary insects (*Acheta, Grylus*) live in warm places. The paired antennae are long (Fig. 16.90E). The elongated ovipositor is spear-shaped. The sound producing stridulating apparatus consists of a scraper in the base of one wing and a file on the base of other wing. As the wings vibrate rapidly the file rubs over the scraper to produce the characteristic chirping sound. A kind of cricket, called the mole cricket, *Gryllotalpa* (Fig. 16.90F) has stout and clawed prothoracic legs for the purpose of digging.

STICK AND LEAF INSECTS. These insects have perfectly copied the structures of branches and leaves of the trees (Fig. 16.90 G & H). Such mimicry protects them from enemies. The females exhibit more accurate mimicry than males. In general these large-sized herbivorous insects are provided with distinct eyes and multi-jointed antennae. The stick insects (*Diapheromera, Carusius*) may be 30 cm in length. The mesothorax is the largest segment. The legs and other parts of the body assume branch-like appearance. Similarly in leaf insect (*Phyllium*), the wings and other parts of the body extend to be leaf-like. The eggs resemble the appearance of seeds and newly hatched youngs also exhibit mimicing features. It gradually increases in size with each moulting.

EARWIG. These insects (*Forficula auricularia*) (Fig. 16.90 I & J) are usually nocturnal and carnivorous. The terminal part of the abdominal appendages are forceps-like. The mouth parts are built for chewing. The fore wings are small and the hind wings are large. The females brood over the eggs.

TERMITE. Nearly 1400 different species of termites are known. The common termite which builds clay nests of great height is known as *Odontotermes redemanni*. The termites are pale-coloured and usually blind. It possesses comparatively large head, chewing and biting mouth parts and bulky abdomen. The chitinous skin is

soft, delicate and highly sensitive. A constriction is visible between thorax and abdomen. Two pairs of similar wings are laid flat on the body during rest. Termites lead a colonial life and exhibit polymorphism. Following forms (Fig. 16.91 A–E) are seen in a termite nest: (1) *Queen*, (2) *Males*, (3) *Workers*, (4) *Soldiers* and (5) *Nasutes*. The workers, soldiers and nasutes are without reproductive organs. The workers constitute the majority in a colony. These small-sized forms do all the duties for the colony excepting reproduction. The soldiers are more or less pigmented and possess large head with powerful mandibles. The nasutes are seen only in a few genera. The head in them is continued as a rostrum, at the tip of which opens a frontal gland. The secretion of this gland helps to prevent enemies and at the same time it dissolves hard substances including concrete structures.

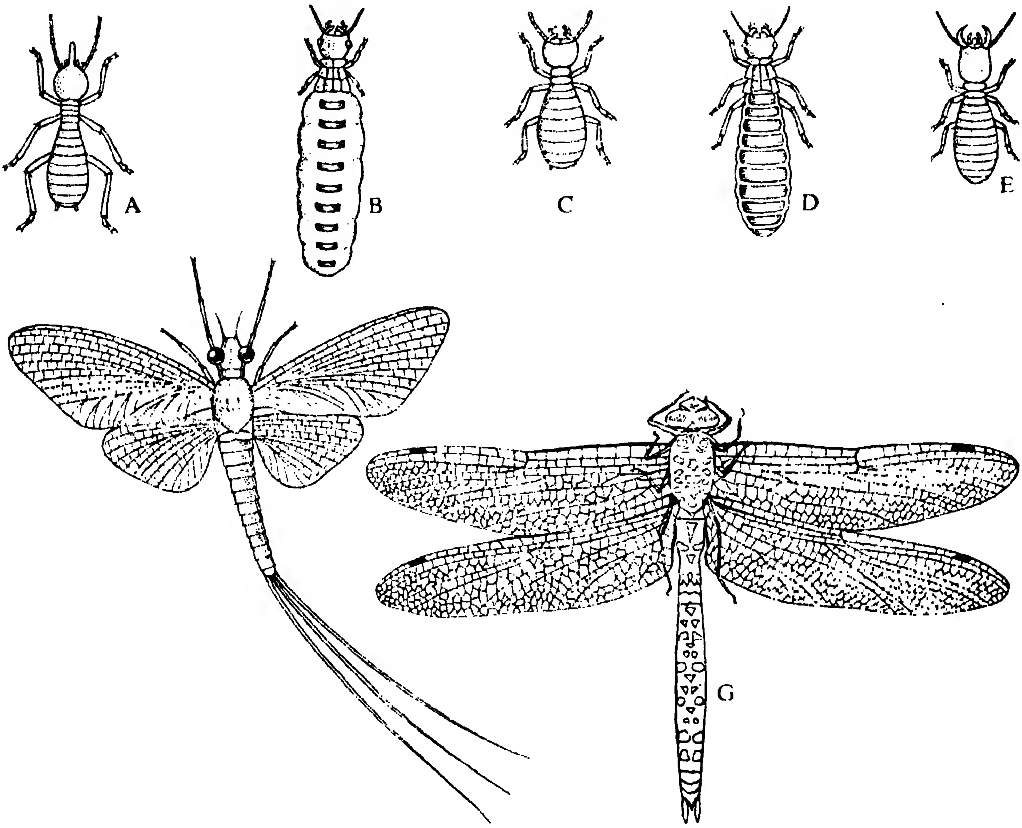


Fig. 16.91. A–E. Different forms in a termite colony. A. Nasute. B. Queen. C. Worker. D. Male. E. Soldier. F. Mayfly—adult. G. Dragon fly.

A termite nest presents highest form of architecture and within the nest there is a special chamber where the queen and a few males are confined. The special chamber is called nuptial chamber. These sexually matured forms have wings longer than the body. Body is usually pigmented and may be yellow, brown or black. The widely separated large compound eyes and paired ocelli are usually present. In addition to these sexually matured forms two other kinds—*substitute* forms and *wingless* forms, are also seen in the colony. The substitute forms have short pad-like wings, ocelli and rudimentary compound eyes. In the wingless forms the wings and eyes are totally absent and the reproductive organs are less developed. The queen is specially fed and it grows to a large size. This large size is due to the enormous growth of abdomen. Within the colony, the queen produces a large number of eggs, most of which develop into sexless workers and soldiers.

But at the end of winter several sexual forms appear. When matured these winged forms take colonising flight, which occur during rainy season. The wings in them extend beyond abdomen and are membranous. During flight most of them are either eaten by birds or destroyed. But some of them drop in the ground and become wingless. They dig a nest in the ground and the females lay eggs. The forms which hatch from these eggs are first alike but gradually transform into workers and soldiers. These forms take charge of the nest and take proper care of their parents. They expand the nest and make adequate arrangements to accommodate the growing population.

The workers and soldiers leave their nest at night to attack furniture, woods and books. Thus they damage human properties in several ways. The only way to get rid of termite menace is to destroy the queen. In spite of its destructive role, the termites are considered important from the point of view of agriculture. Like earthworm, the termites also pulverise the soil and make it fertile. Swarming termites are taken as food by birds and other animals.

MAYFLY. The mayflies, *Ephemera* (Fig. 16.91F) are noted for two unique features (*i*) winged adult stage has a life span of one day and (*ii*) moulting occurs in a winged form. The adult aerial form has two pairs of unequal membranous and triangular wings. The abdomen ends in long cerci which may or may not have median terminal filaments. The adult dances in air and lay eggs in water. The development continues almost for a year and involves twenty-three moultings before the emergence of adult state. The aquatic larvae are free-swimming and possess rows of tracheal gills on each side of the abdomen for respiration. Finally, they break the nymph wall and come on land to rest in some places like trees or walls. Another moulting of this winged form liberates the full-grown adult.

DRAGON FLY. These are usually large-sized insects. The common genera are *Macromia*, *Aeschea*, etc. It is provided with chewing mouth parts and membranous wings. Sometimes the hind wings are larger than the fore wings. At the time of rest, the wings are held horizontally (Fig. 16.91G). The compound eyes are quite prominent but the antennae are short. The abdomen is elongated, slender and thread-like. The dragon flies are predators and hunt other insects like a kite. The mating takes place during flight and the eggs are released in water. The larvae called *nymphs* are aquatic and respire through a special kind of aquatic gills. The elongated labium is provided with hooks and remains folded during rest. It is extended rapidly during food capture.

BED BUG. These sanguinivorous ectoparasites live in close association with man and are cosmopolitan in distribution. Number of diseases, i.e. anthrax, leprosy, paratyphoid, oriental sore are believed to be caused by bed bug (*Cimex lectularius*, *C. rotundatus*). The beddings, furniture and crevices of the room are the favourite abode of these insects. The warmth as well as the smell of the host attracts them and the bed bugs are active specially during night. The adults (Fig. 16.92A) are 4–5 mm in length and 3 mm in breadth and are reddish brown in colour. Flat and oval body is profusely covered with bristles and hairs, short head possesses, distinct paired compound eyes and a pair of four-jointed antennae. The mouth parts are adapted for piercing and sucking. For that purpose, the mouth parts have formed a proboscis which encloses needle-like maxillae and mandibles. When not in use the proboscis is kept folded on the ventral side of the body. The prothorax is semilunar and the mesothorax is triangular. The pointed end of the mesothorax is directed backwards and it bears atrophied first pair of wings. There is no trace of second pair of wings. The abdomen is flat and contains eight distinct segments. In males, the abdomen is more pointed. A curved penis is lodged in a deep groove in the left side of the eighth abdominal segment. The stomach serves as a crop and stores blood during meal. This blood may be retained for several weeks. The saliva, which mixes with the blood meal, contains anti-coagulating enzymes which keep the blood liquid. The digestion takes place in the intestine. The first part of the mid gut is formed by vacuolated cells and is concerned with the absorption of fluid from the meal. Only a little haematin material passes within the hind gut. The blood cells or haemocytes of bed bug do not enter within the cavity of the heart. The haemocytes remove debris from haemolymph at the time of moulting. It can live for weeks

without food and water. Lack of water leads to the formation of dry yellow urine. The inner surface of sternum in mesothorax carries paired stink glands,

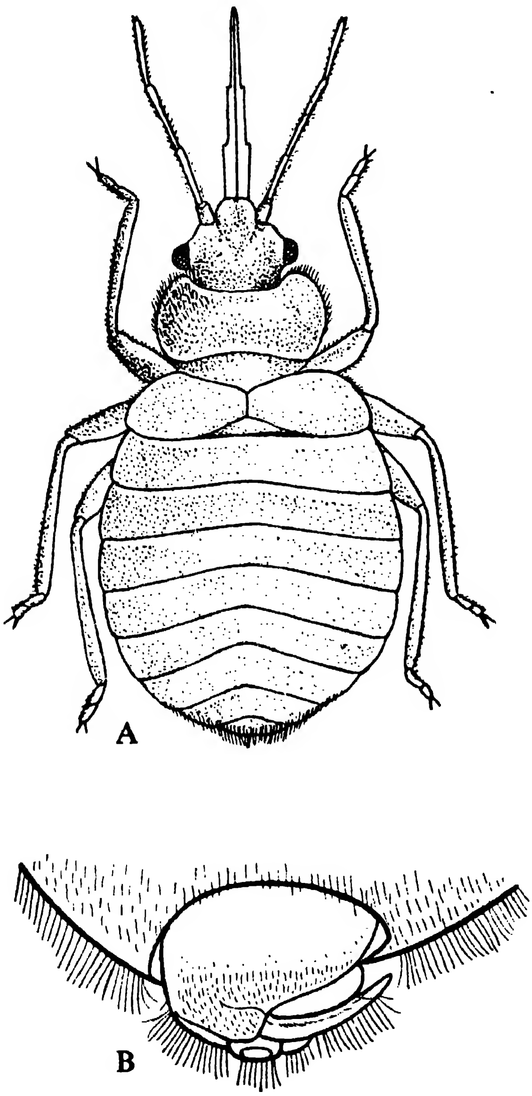


Fig. 16.92. A. Bed bug (*Cimex*) dorsal view. B. General segment of male, ventral view.

which produce characteristic smell of the bed bug. The secretions of these glands are transparent, oily, volatile and strongly acidic. The secretions are released through a pair of median apertures. The stink glands of nymph stage are abdominal in position and three in number. In the adult stage, these glands atrophy and new thoracic glands appear. The genital segment of male, at the posterior end of the abdomen, is provided with a pointed clasper (Fig. 16.92B). During copulation, the sperm cells are deposited in a pouch on the lower surface of the female abdomen. These cells reach the genital tract after travelling through the general body cavity. Most of the eggs are fertilized, when still in the ovary. The eggs when laid are glued to the substratum by a mucilagenous coating. The young hatches out by lifting a lid on the egg called operculum. The metamorphosis is incomplete and the young is called nymph. Such nymphs are yellowish white and 1·5 mm in length. The growth and conversion to adult structure involve five moults. Nymphs are also able to suck blood and it is believed that the distension of the abdomen of nymph due to blood meal causes moulting.

LOUSE. Three kinds of lice are seen—*Book lice* (Fig. 16.93A), *Biting lice* (Fig. 16.93D) and *Sucking lice* (Fig. 16.93B & C).

The book lice includes numerous kinds of species. These are minute, insignificant and soft bodied insects having peculiarly modified biting mouth parts. Though they are called book lice, majority of them live on trees and only a few live within old papers. Two pairs of wings are membranous and have characteristic pattern of venation. At the time of rest the wings are held roof-like over the abdomen.

The biting lice include more than 2500 species, all of which live as ectoparasites on birds and mammals. The body is flat and covered with bristles. The wings and compound eyes are absent. The mouth parts are adapted for biting but much reduced. Food usually includes the feathers or hairs of the hosts but some are blood-suckers. Eggs are glued with the feathers or hairs of the host and the larvae are also ectoparasites. Development involves three moultings.

The sucking lice are exclusively ectoparasitic. All are blood-suckers and for that purpose the mouth parts include thin stylets within a cephalic sac. The wings and eyes are absent. All the thoracic legs have well-developed claws. The human head and body louse is known as *Pediculus humanus*.

LAC INSECT. The lac insects are scientifically known as *Tachardia lacca*. Previously, the genus *Tachardia* was known as *Kerria*. Two species under the genus are very

common—*K. lacca* and *K. chinenses*. Of the species, *Kerria* (*Tachardia*) *lacca* is the common Indian variety. India is the highest lac-producing country. Thailand comes next to India regarding lac production. These insects live on certain specific

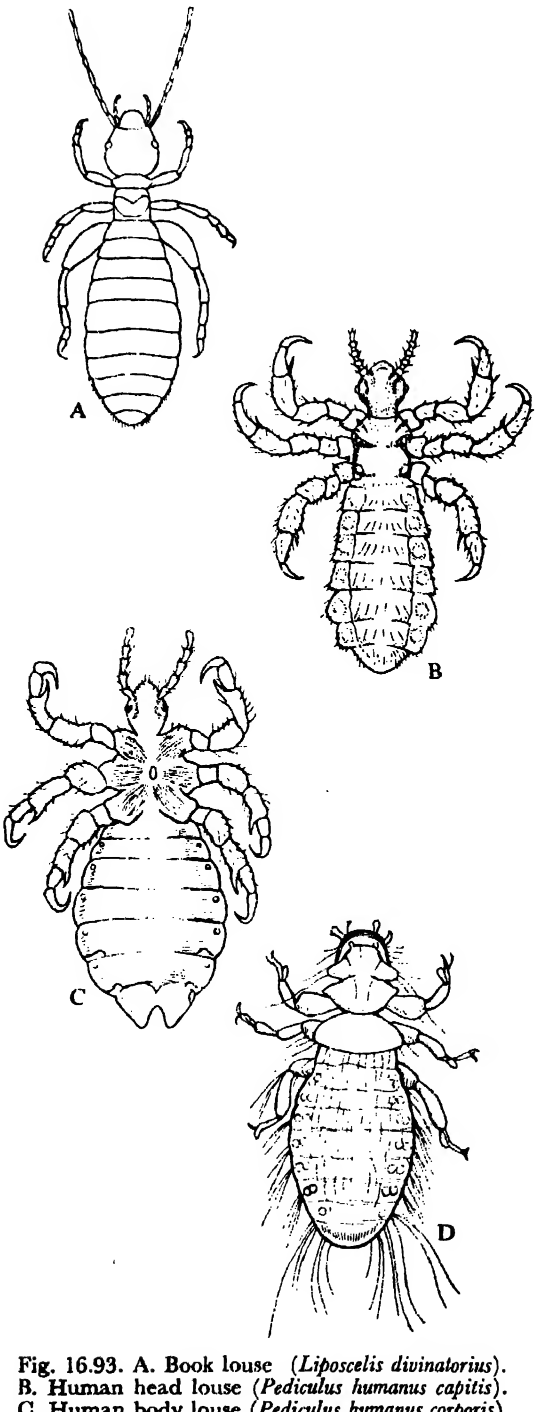


Fig. 16.93. A. Book louse (*Liposcelis divinatorius*). B. Human head louse (*Pediculus humanus capitis*). C. Human body louse (*Pediculus humanus corporis*). D. Chicken louse (*Menopon pallidium*).

trees like kusum, khair and ber (kul). It liberates a resinous product as exudate which forms a crust around the insect. From this exudate a product called *lac* is obtained. Thus, lac is regarded as resinous secretions produced by the female members of the lac insect. In order to obtain lac, these insects are cultured and the technique of lac production is called *lac culture*. It involves proper care of host plants, regular prunning of the host plants, propagation of insects and collection and processing of lac. For the purpose of propagation the older branches (approximately 23–30 cm) containing crusts are tied with new branches and this method is called *inoculation*. When new crusts are formed, most are collected and this collection is known as *harvesting*.

According to its harvesting season, the lacs are classified into two types—(1) *Kusmi lac*. It grows on kusum trees and is inoculated in January-February and hervested in June and July of the following year. (2) *Ranjeeni lac*. It grows on other trees excepting kusum. The inoculation time is October-November and harvesting time is May-June. The kusum trees being much larger in size, provides more surface area and thus the yield of Kusmi lac is higher than the Ranjeeni lac.

After inoculation, lac insects come out of the old crusts. At this stage they are known as *nymphs*, which have hatched out from the eggs, laid by the females in the old crusts. When nymphs vacate the old crust, the crust is called *Phunki*. The phunki must be removed within three weeks from the date of inoculation, otherwise it will be susceptible to parasitic infection. The coming out of nymphs from older crust is called *swarming*. These nymphs are boat-shaped and reddish in colour. Each nymph possesses three pairs of thoracic legs, one pair of antennae and a pair of caudal setae. Some of the nymphs become winged or wingless male and others become female (Fig. 16.94). These nymphs explore new branches. It sucks cell sap by piercing the branches with the help of specialised maxillae and mandibles. The nymph settles in a suitable spot and liberate a kind of exudate. The nymphs gradually lose most of its body structures and undergo repeated moulting. The thrown out skin together with the exudate form a crust around it. Each crust contains a pair of *branchial pores* for respiration and

a big *anal tubercular opening*. In male, the tubercular opening is provided with an operculum. After three moultings the males come out by removing the operculum and copulate with the female.

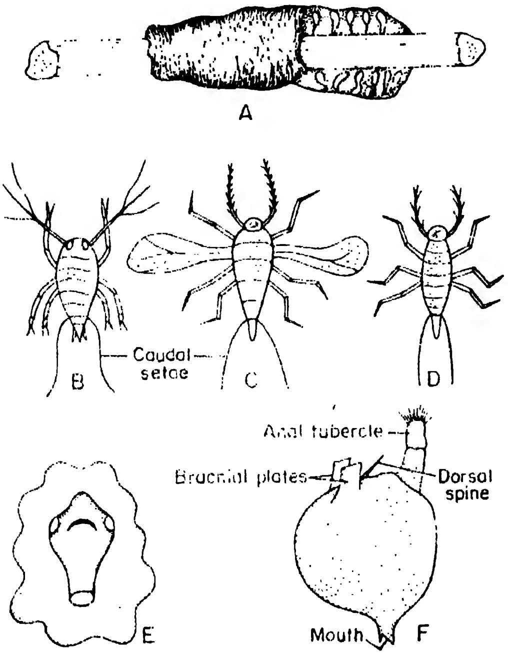


Fig. 16.94. Lac insect (*Tachardia lacca*). A. Incrustation of lac around a twig, B. Nymph, C. Male (winged), D. Male (wingless), E. Female (adult in incrustation) and F. Female (adult—free from incrustation).

The males are devoid of mouth parts for this reason they die soon after copulation. Most of these crusts are removed at the time of harvesting and are used for extracting lac. As the males are short-lived, they produce lesser lac than the female. The production of lac is good, if the ratio of male and female remains 30 : 70. If number of male increase in a particular year, the crop is said to be poor.

Extraction of Lac

The mature incrusted twig is cut. Then the incrustations are washed thoroughly and scraped to remove the secreted materials. These materials constitute the granular lac which is dried and bleached in the sun. The granules are taken in suitable pot and heated by open charcoal fire. During heating the lac is forced out as it melts. Pigments can be used as dyes at this stage. In molten condition, these materials are stretched into sheets. After drying these sheets are broken into flakes.

Uses of Lac

Lac has great commercial value. It is extensively used in the manufacture of:

(*i*) Lithographic ink,
(*ii*) Varnishes and polishes,
(*iii*) Sealing wax,
(*iv*) Electrical insulating material,
(*v*) Shoe polishes, toys, ornaments, etc.

BUTTERFLY. For their colourful texture and elegant movement, these daytime flying insects are regarded as the symbol of grace, beauty and austerity. The head bears two large compound eyes, each with numerous ommatidia. A pair of club-shaped antennae, characterise the butterfly. The butterflies have two pairs of large wings which at the time of rest are held high over the body, like sails of a boat. The equal-sized wings are provided with hairs and scales. The sucking type mouth parts are formed by a long-coiled proboscis. It is formed by the union of two halves of a tube, each half represents the outer part of maxilla. The proboscis remains coiled, when not in use, under the head and extends during use. The mandibles are insignificant. Labium is absent but the labial palp is well extended. Each type of butterfly has preference for a particular plant to lay eggs.

The larva after hatching out of egg often eats voraciously. The larvae, which are called the caterpillars (Fig. 16.95), have powerful mandibles, three pairs of jointed thoracic legs and four to five pairs of unjointed abdominal legs. The growth of caterpillar involves the shedding of old cuticle. Within a fortnight the caterpillar sheds its skin repeatedly and becomes full-grown. After certain period of growth the caterpillar produces around its body a covering and becomes sedentaric pupa. The secretion is produced by special silk glands which are present in the body of caterpillar. The pupa is also known as *chrysalis* and it possesses a slender stalk. Rapid transformation of body parts occur within pupa. Various caterpillar structures are then replaced by the appearance of adult parts. On completion of the development, the butterfly emerges by breaking the pupal case. Immediately after coming out, the body remains soft. Following butterflies are well-known in our country.

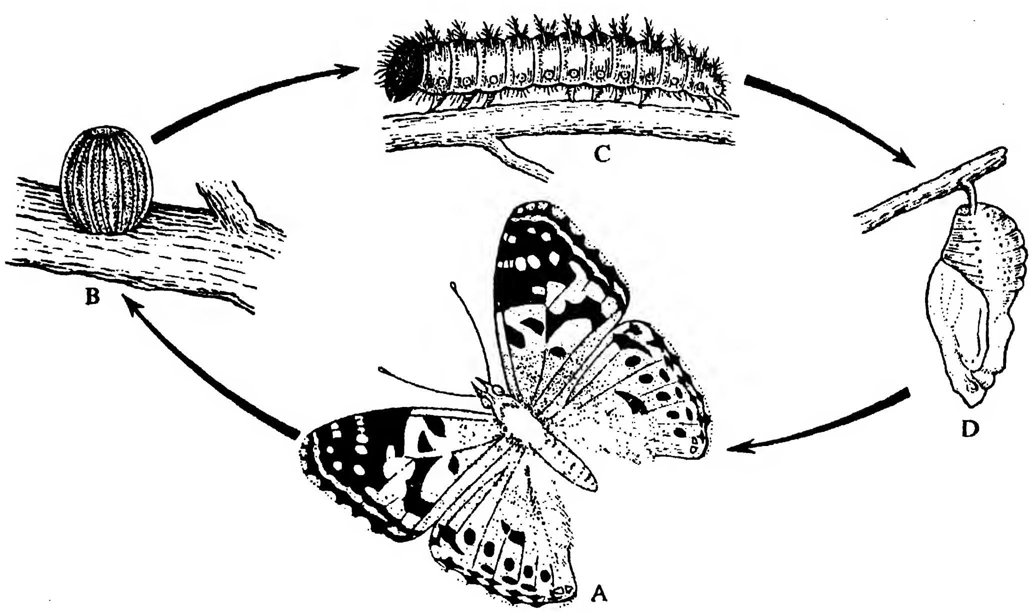


Fig. 16.95. Life history of a butterfly. A. Adult. B. Egg. C. Caterpillar. D. Pupa.

COMMON WINDMILL (*PARIDES PHILOXENUS*). These beautiful velvety black coloured butterflies (Fig. 16.96A) are found in the Himalayan region specially in Assam. The size is 11 to 15 cm across. The anterior wings are smooth in outline but posterior wings are peculiarly notched. The posterior wings are also marked by beautiful red spots. *KRISHNA PEACOCK* (*PAPILIO KRISHNA*). These large butterflies (Fig. 16.96B) with wingspan of 10 cm have beautiful green texture with red, yellow and blue markings. They are quite common in the Himalayan region, specially in Sikim and Bhutan. The posterior wings are peculiarly lobed. *KAISER-I-HIND* (*TEINOPALPUS IMPERIALIS*). These rare butterflies (Fig. 16.96C) of Assam, Nepal and Sikim exhibit sexual dimorphism. Males have a single tail but females have three. They generally live on the top of the tree and on rare occasions come to the ground. *RICE BUTTERFLY* (*MELANITIS ISMENE*). These deep brown coloured, shade-loving butterflies (Fig. 16.96D) are quite common in India. They lay eggs on paddy plants and have characteristic coloured eye spots at the centre of the wing. The caterpillars are green. *CABBAGE BUTTERFLY* (*PIERIS BRASSICAE*). These white, yellow or organge-coloured butterflies (Fig. 16.96E) are often seen in agricultural fields. They lay eggs on cabbage and other plants under Cruciferae and pupa remains in upright position. These are migratory in nature.

BEETLES. These are insects with hard integument and chewing mouth parts. The prothorax is large and movable. The stiff and hard anterior wings known as elytra cover the posterior wings completely. Some are wingless. It exhibits complete metamorphosis and larvae are provided with well-developed head, biting mouth parts and three pairs of legs. Following beetles are very interesting: *LEAF BEETLE.* These oval bodied beetles (Fig. 16.97A) are provided with short antennae and small legs. It lives upon leaves of various plants like potato, cucumber, etc. *LONG-HORNED BEETLE.* Eleven segmented antennae of these beetles (Fig. 16.97B) are longer than the body. Larvae are wood-borers. *DERMESTIDE.* These small, more or less round beetles (Fig. 16.97C) are noted for their habit of feigning death. These beetles are commonly seen in the fur of museum specimens, carpets, woolen dresses and in different other domestic goods. Its abdomen remains fully enclosed by the elytra. The well-known examples are *Anthrenus*, *Dermestes*. *LADY BIRD BEETLES.* These beneficial insects (Fig. 16.97D) destroy aphids and other plant pests. They have beautiful red-coloured bodies with black spots on it. They are distributed

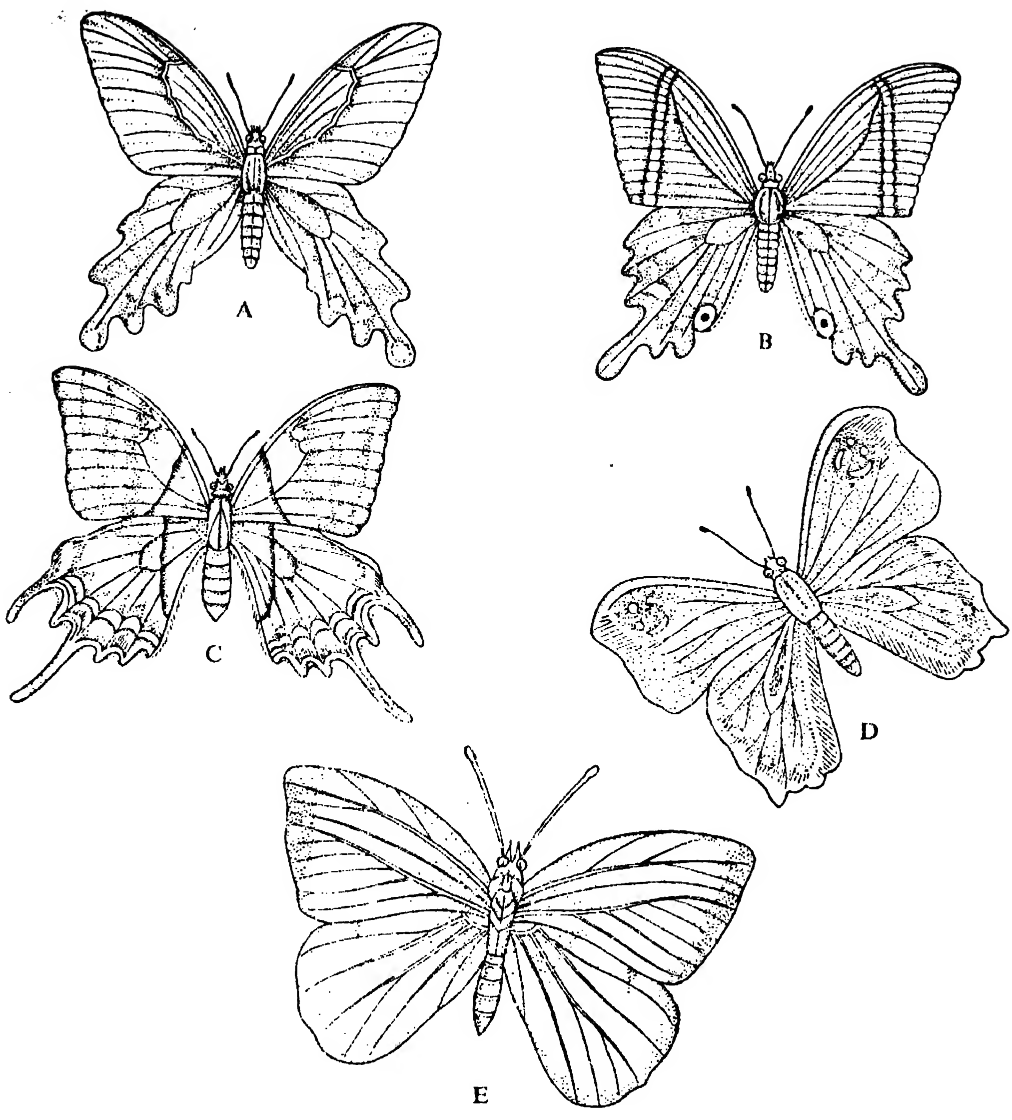


Fig. 16.96. A few common butterflies. A. Common windmill (*Parides philoxenus*). B. Krishna peacock (*Papilio krishna*). C. Kaiser-I-Hind (*Teinopalpus imperialis*). D. Rice butterfly (*Melanitis ismene*). E. Cabbage butterfly (*Pieris brassicae*).

throughout the world. *WATER BEETLE.* These large aquatic beetles are seen throughout the world in fresh-water ponds, lakes and pools. Their food includes small fishes, aquatic insects and other small aquatic organisms. The adults have thread-like antennae, oar-shaped hind legs and they can fly well. While diving inside water they carry a film of air beneath their wings. The large-sized, whirligig beetle (Fig. 16.97E) at the time of diving carries a bubble of air at the posterior end of the body. The larvae possess strong mandibles and long abdomen. *FIRE FLIES.* These beetles (see Fig. 8.10B) are well known for their ability to emit light. For this purpose, they possess phosphorescent organs which are present in the posterio-ventral aspect of the abdominal segments and are in connection with trachea. A substance *luciferin* is present in this organ, which is oxidised in the presence of an enzyme *luciferase* to produce light in them which is without heat. *WEEVILS.* These beetles have peculiar elongated head which is drawn to form a rostrum. These are highly injurious to plants, fruits, seeds and stored grains. The well-known

examples are—rice weevil (*Calandra oryzae*), mango weevil (*Apion* sp.). *DUNG ROLLER.* They are also known as *scrab beetle* and was considered sacred in ancient Egypt. They are well-known for their parental care. They prepare small spheres by rolling dung and eggs are laid on them by the females. These balls are deposited in a hole. When the grub comes out it uses the dung as food.

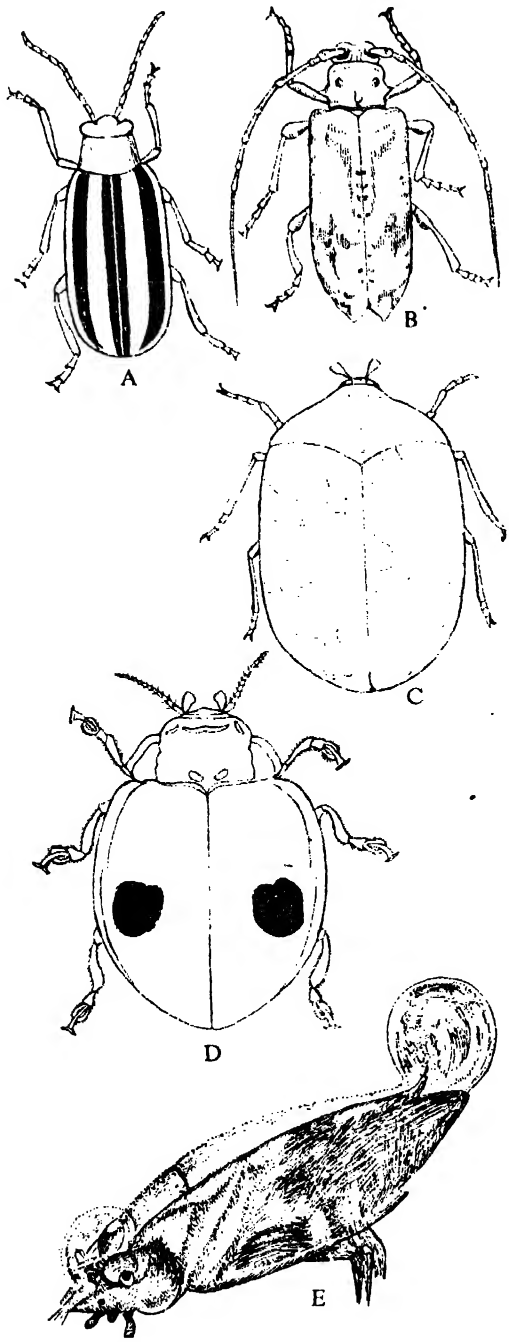


Fig. 16.97. Some important Beetles. A. Leaf beetle (*Acalymma vittata*). B. Long-horned beetle (*Acanthoderes decipiens*). C. Dermestide (*Anthrenus scrophulariae*). D. Lady bird beetle (*Adalia bipunctata*). E. Whirligig beetle (*Gyrinus*).

WASP. Two kinds of wasps are well-known—Spider wasps and Hornets. The spider wasps are large, active, long-legged and hunt spiders. These wasps build underground burrows and place a paralysed spider within it. One egg is laid on each spider. When the larva hatches out, it eats the spider. The hornets live on nectar, ripe fruit, sugary fluid and also eat larvae and small insects. Some are solitary but many exhibit highly organised social life. A family includes queen, males and workers. After copulation, the queen hibernates for a year and then starts to lay eggs. First lot of eggs develops into workers and then queens and males emerge. Its nest is papery and has several tiers and the entire nest is enclosed within an outer envelope.

ANT. Ants are well-known example of the insects which exhibit polymorphism. Like termites and bees, they also lead a social life. There exists innumerable types of ants (nearly 3,500 species) which abode various places from burrows to specially formed nests. In ants the abdomen is distinctly separated from thorax and antenna is divided into an unjointed basal part and a many-jointed upper part. Colony of ants includes following forms—female or queen, male or king, workers and soldiers. Only the males and the females possess transparent wings and enter into nuptial flight. At the end, they lose their wings and the female lays eggs. From each egg an elongated legless grub is developed which transforms into pupa. These pupae develop into workers which start to take care of the nest. As in bee the unfertilized eggs produce males and fertilized eggs give rise to workers and females. The workers are wingless and possess female gonads in arrested state of development. Some workers undergo special modification in their structures to act as soldiers. The workers do all sorts of work and the males and the females are dependent on them. The job of the workers include collection of food, protection of the nest, rearing of grubs and pupa, cleaning of the nest. It has now been determined that a

substance called *pheromone* guides the foraging workers to identify the way to its own nest. Some ants are known to rear insects like beetles, aphids in their nests. Specially these aphids when touched by the antennae of ant secrete a juice and for this reason they are known as ant-cow. The well-known ants (Fig. 16.98 B & C) are common red ant (*Oecophyla smaragdyna*), black ant (*Componotus compressus*), European wood ant (*Formica rufa*), etc. Ants often destroy vegetations but at the same time they are effective pollinating agents. Several ants kill caterpillars, bugs and beetles and thus serve as important agent for biological control.

FLEA. These insects in their adult stage live as ectoparasites on birds and mammals. Nearly 1500 species are known. The body is laterally compressed, brown and strongly sclerotised (Fig. 16.97D). The head is small and the mouth parts are

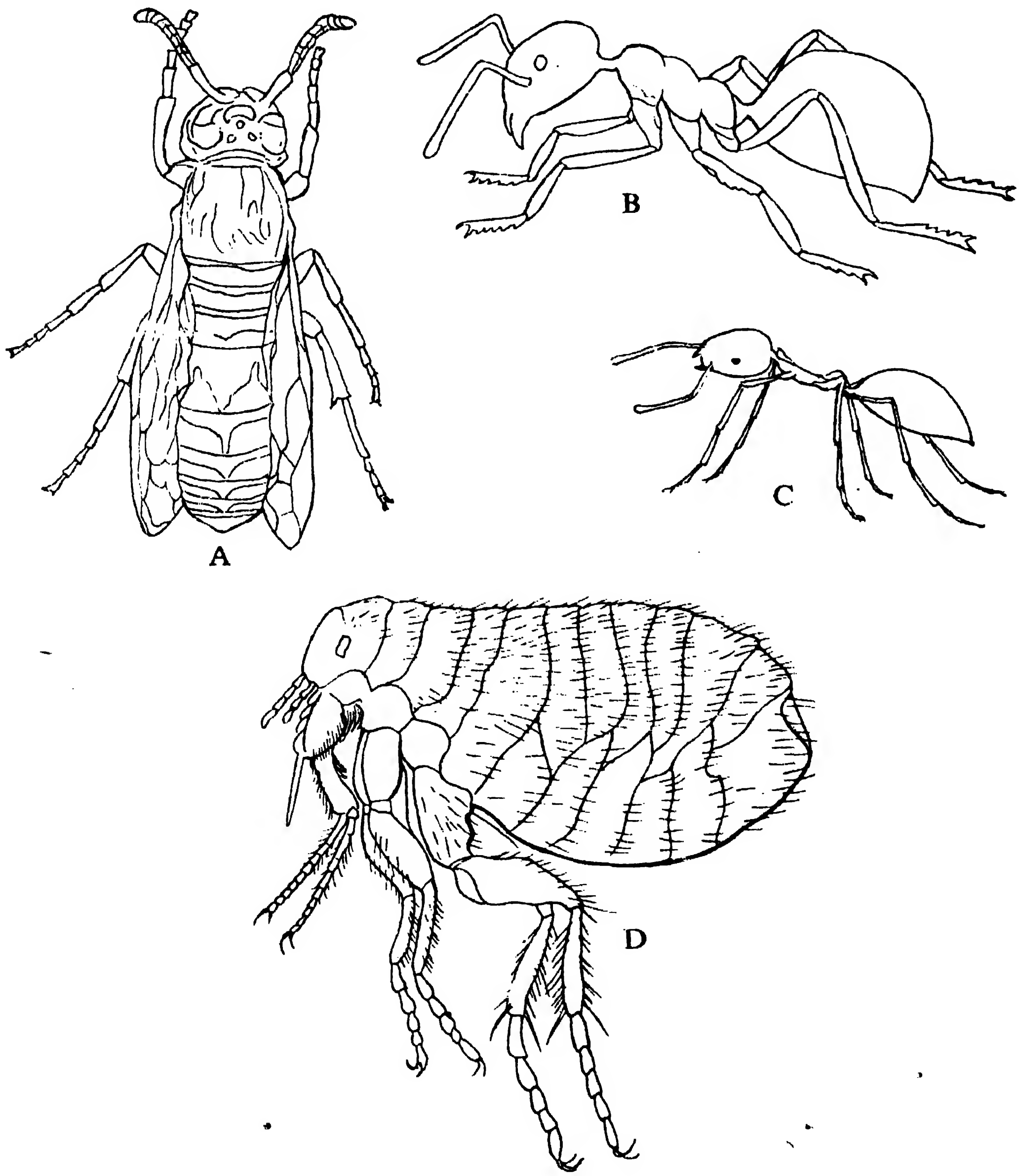


Fig. 16.98. A. Hornet—a kind of wasp. B. Black ant (worker). C. Red ant (worker). D. Rat flea, Not drawn up to scale.

adapted for piercing and sucking. All are sanguinivorous. The wings are absent, but the legs are well developed and specially the hind legs are adapted for leaping. A female flea lays nearly 300–500 eggs. The larvae are white, small and worm-like. The head of the larva carries a spine, which breaks open the egg shell at the time of hatching. The larva is free-living. The next stage pupa covers itself with a silken cocoon, impregnated with sand grains and debrises.

The most notable flea is rat flea (*Xenopsylla cheopis*) which carries a bacterium (*Pastaurella pestis*) from infected rats and causes Bubonic plague in man. The same flea also infects another disease called endemic typhus. The other important fleas are *Pulex irritans* (human flea), *Ctenocephalides felis* (cat flea) and *Ctenocephalides canis* (dog flea).

Example of the Phylum Arthropoda—*Horse-shoe Crab*

The horse-shoe crab includes three genera, *Limulus*, *Tachypleus* and *Carcinoscorpius*. It belongs to the order Xiphosurida and is included under the class Merostomata. The largest horse-shoe crab is *Limulus polyphemus*, which measures 60 cm in length (including caudal spine).

Habit and Habitat

These marine animals are bottom dwellers in shallow water. During breeding season, both male and female come on land and dig holes at the upper limit of high tides to lay eggs. It can dig by the help of *cephalothorax* and may remain completely buried. The full-grown horse-shoe crabs usually crawl by using the legs, while the youngs can swim invertedly with the help of abdominal appendages.

External structures

As its name indicates the body is horse-shoe-shaped. It is divisible into two parts *cephalothorax* or *prosoma* and *abdomen* or *opisthosoma* (Fig. 16.99). The abdomen extends posteriorly as *caudal spine*. Both the thorax and abdomen are unsegmented and are covered dorsally by exoskeleton. The abdomen remains movably articulated with the cephalothorax. In contrast with the hard dorsal exoskeleton, the ventral side contains soft sclerites in between the appendages.

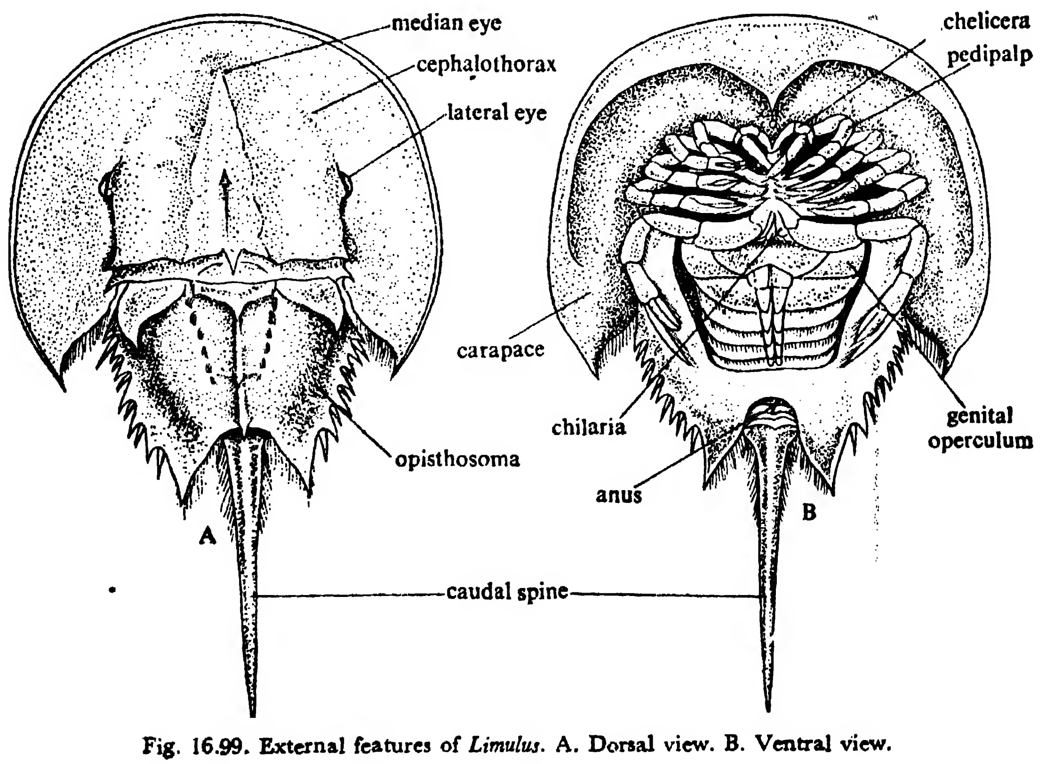


Fig. 16.99. External features of *Limulus*. A. Dorsal view. B. Ventral view.

CEPHALOTHORAX. The cephalothorax is formed by the fusion of cephalic region and six appendage-bearing thoracic segments. Lines of segmentation are absent and the thoracic appendages are closely approximated. The dorsal exoskeletal covering, *carapace* is more or less semicircular in outline. It is drawn at the postero-lateral ends into pointed projections. Following structures are seen in the cephalothorax: (1) SPINY RIDGES. One *median* and two *lateral* spiny ridges are longitudinally disposed on the dorsal side. The median ridge has two grooves, one on its either side, which run longitudinally to continue along the abdomen. (2) EYES. Two pairs of eyes, *median* and *lateral* are present on the carapace. The median eyes are small and simple eyes. These are placed anteriorly, one on each side of the median ridge. The lateral eyes are comparatively larger and compound in nature. Each lateral eye is placed on the outer side of each lateral ridge. (3) MOUTH. This aperture is present within a depression on the ventral side and bounded on all sides by the processes of cephalothoracic appendages. (4) FRONTAL ORGAN. It is a wart-like structure in front of the mouth. In larva, it acts as photoreceptor, but its function in adult is unknown. (5) APPENDAGES. Six pairs of tube-like distinct appendages are arranged like a ring on the ventral side. The first pair is known as *cheliceras*. In adult, it is a preoral appendage. Each chelicera is slender, trisegmented and situated in the anterior border of the mouth. The distal article is chelated. The second pair is called *pedipalpi*. It is more or less leg-like and jointed. The proximal segment is spiny and the distal one is chelate. It helps in food capturing and locomotion. The third to sixth pairs of appendages are *walking legs*. The walking legs serve both the functions of locomotion and food procurement. For the purpose of ingestion, the bases of the legs are drawn into spiny lobes, called *gnathobases* (Fig. 16.100) which remain radially arranged around the mouth. The last pair, in both the sexes, is non-chelate and bears four movable *spines* at the distal tip. These spines act as shovel for removing loose sand. In addition, the outer border of its base bears a *spatulate process*. A pair of small, flat, coxa-like appendages called *chillaria* are present. It remains directed vertically downwards and represents the degenerated seventh pair.

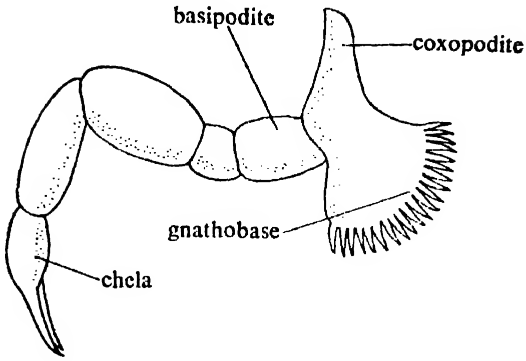


Fig. 16.100. One walking leg of *Limulus*.

ABDOMEN. The abdomen looks like a hexagon. At the anterior end, the three sides of the hexagon form a lens-shaped hinge to articulate with the cephalothorax. In the posterior end of the abdomen lies a notch for the articulation of *caudal spine*. On the dorsal groove of the abdomen there are six pairs of *depressions* and six pairs of laterally projected *spines*. Such depressions and spines denote the position of segments. Six pairs of *appendages* are present in the ventral side of the abdomen. Each appendage is lamellar and consists of a narrow inner process and a wide outer plate. The first pair of abdominal appendage is without gill. It is united at the middle to form *genital operculum* which carries *genital pore*. The remaining five pairs are free from one another and each carries a *gill* or *branchial lamella*. The abdominal appendages beat slowly but continuously. At the time of swimming the speed becomes accelerated.

CAUDAL SPINE. It is a long posteriorly projected pointed structure, which remains movably articulated with the abdominal notch. It does not represent the telson but is considered as an appendage of the telson.

Integumentary system and Endoskeleton

As in other arthropods, the thick exoskeleton consists of *epicuticle* and *chitinous cuticle*. The cuticle is devoid of calcareous material. Posteriorly there are six pairs of *apodemes* for the attachment of abdominal muscles. These are mesodermal cartilaginous plates inside the body cavity. In the

cephalothorax, there is an *endosternite* for the attachment of leg muscles, but in abdomen there are six pairs of *dorsal* and six pairs of *ventral endosternites*.

Digestive system

It includes (1) *alimentary canal* and (2) *digestive glands*.

ALIMENTARY CANAL. The alimentary canal begins from a slit-like *mouth* between the gnathobases of 2–5th cephalothoracic appendages. It leads into a cuticularised *pharynx*. The pharynx forms a loop and opens into a dilated *proventriculus* or *gizzard*. The wall of the gizzard is muscular and its inner part is ridged and raised as *denticles*. The gizzard communicates to a short and straight *intestine* and the opening is guarded by a funnel-like valve. From the intestine arise two pairs of branched *caeca*, which occupy major part of the cephalothorax. The intestine ends in a short *rectum*. The rectum opens to the exterior by an aperture called *anus*. The anus is present near the base of caudal spine.

DIGESTIVE GLANDS. The *intestinal caeca* serve as the digestive glands. The digestive juice is alkaline and contains various enzymes to split the complex food.

MECHANISM OF NUTRITION. The horseshoe crab hunts at night. The foods include worms and molluscs. The chela of the legs bring the food to the gnathobases, which in turn force it to enter into the mouth. The food is swallowed intact. The gnathobases of the last appendage may break the shell. The chilaria pushes the food forward. The chewing takes place within the gizzard, from where, excepting bones and shells, other substances enter into the intestine. The unwanted shells and bones are again regurgitated from the mouth. The digestion takes place mostly in the caeca and nutritive substances are also absorbed in its wall. The residual matters pass through the anus as faeces, which may be 5–10 cm long.

Respiratory system

The respiration takes place in aquatic medium. The respiratory organs are known as *gills* or *branchial lamellae*. These are present in association with the last five pairs of abdominal appendages. Each lamella is borne on the exopodite part of each leg and consists of 150–200 delicate, richly vascularised leaf-like structures. The abdominal appendages move constantly to flow current of water which bathes the vascularised leaves of the gills.

Circulatory system

The circulatory system includes *heart*, *arteries*, *sinuses* and the circulating fluid *blood*.

The *heart* is present on the dorsal side of the intestine (Fig. 16.101). It is fusiform in appearance and extends almost the entire length of the body. It is enclosed within a *pericardial sinus*. Heart communicates with this pericardial sinus by means of eight pairs of *ostia*.

A *median ventral artery* and a pair of *lateral arteries* arise from heart and run anteriorly. The median artery supplies the dorsal side of the anterior part and the lateral arteries supply its ventral side. These two lateral arteries unite and form a spacious blood sinus, within which lies the brain and suboesophageal ganglion. This sinus extends posteriorly to enclose the ventral nerve cord and its ganglia. From the adjoining regions of the first four pairs of ostia, four pairs of lateral arteries originate. These lateral arteries of each side join to form a *lateral vessel*. These two lateral vessels unite posteriorly and continue as *subabdominal artery* into the caudal spine. From each lateral vessel, near the region of second pair of ostia, an artery arises. This artery splits into one *caecal artery* to supply the caeca and a *marginal artery* to continue along the outer border of the cephalothorax. The two marginal arteries finally unite with the anterior median artery.

The arteries open within haemocoelomic spaces called *lacunae*. Several lacunae unite to form small *sinuses*. From these lacunae and sinuses, deoxygenated blood is finally collected in three large *longitudinal sinuses*. One such longitudinal sinus encloses the intestine and the other two are placed ventrally. From these ventral sinuses, the blood is sent to the gills for aeration. From gills, aerated blood is carried to the pericardial sinus by several laterally placed dorso-ventral sinuses.

The blood is a fluid with dissolved pigment, haemocyanin. Very few cells are seen in it.

Excretory system

The excretory organs are known as *coxal glands*. For its bright colour, it is also

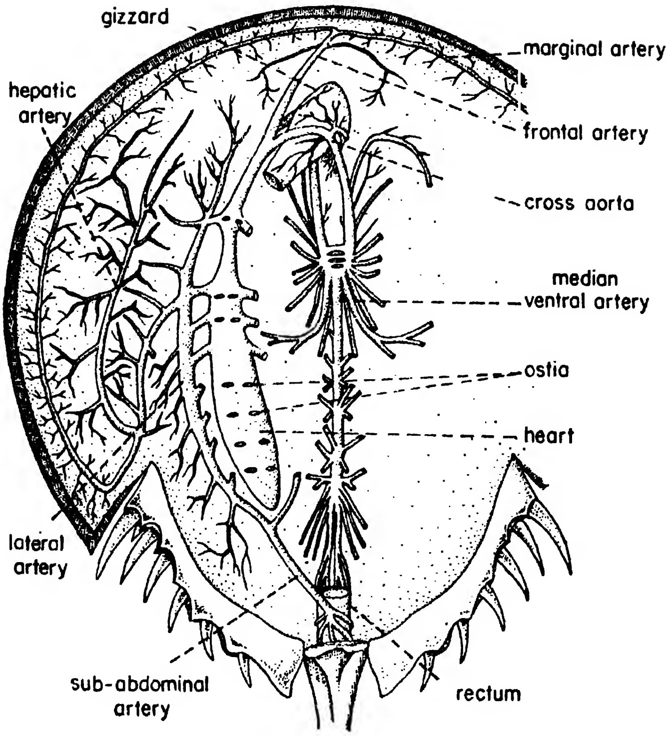


Fig. 16.101. Circulatory system of *Limulus* (after Parker and Haswell).

known as *brick-red gland*. Each gland is four lobed and occupies the ventral side of the endosternite in the cephalothorax. A convoluted *nephridial canal* begins blindly from each gland and unites to form a common passage. It then runs up to the base of the fourth walking leg and forms a vesicle there. From this vesicle arises a common excretory canal which opens to a raised papilla, lying between the coxae of fifth and sixth appendages.

Nervous system

It includes *central nervous system, peripheral nervous system* and *sense organs*.

Central nervous system. It consists of *Suprapharyngeal ganglion* or *Brain, Subpharyngeal ganglion* and a double *Ventral nerve cord*. The brain is oval, compact and divided into two lateral lobes. It is placed anterior to the subpharyngeal ganglion and forms a ring around the oesophagus. The subpharyngeal ganglion is formed by the fusion of ganglia belonging to the second to eighth segments. From the subpharyngeal ganglion arises ventral nerve cord. It runs posteriorly and carries four ganglia in its path, each representing the ninth to fourteenth segments. The last ganglion is formed by the fusion of ganglia belonging to the last three segments.

Several peripheral nerves are given out from different ganglia. The optic nerve, which comes from the eye, opens to the brain.

Sense organs. The sense organs of horse-shoe crab are: (1) *Sensory cells*, (2) *Frontal organ* and (3) *Eyes*.

(1) Sensory cells. These cells are scattered all over the masticatory processes of the thoracic limbs. The sensory cells which are present on the distal article of the walking legs are chemoreceptors.

(2) Frontal organ. This is a specialised hairy area having a diameter of 5–8 mm. The function is not known in adult but serves as photoreceptor in larvae.

(3) Eyes. Among the two kinds of eyes, the *lateral eyes* are better developed than *median eyes*. Each median eye is a simple eye and consists of (*a*) *Lens*—large, spherical and cuticular structure, (*b*) *Corneagen cells*—present underneath the lens and formed by the hypodermis, (*c*) *Retina*—it

includes a central rhabdome and 6–8 irregular sensory cells.

The lateral eyes are *compound eyes.* Each lateral eye (Fig. 16.102) has: (*a*) *Lens.* It is a thick but transparent cuticle, formed by the downward conical projections of hypodermal cells. (*b*) *Ommatidia.* Beneath the lens, the hypodermal layer is modified as ommatidia. Each ommatidium consists of 10–15 cells called *retinulae*, the inner parts of which are modified to form a central *rhabdome.* A central ganglion cell is present immediately beneath the rhabdome. The ommatidia are separated from each other by single layer of columnar cells. From the structure of lateral eye it is evident that these are of much simpler design than the compound eye of other arthropods. The median eyes appear to be degenerated structures.

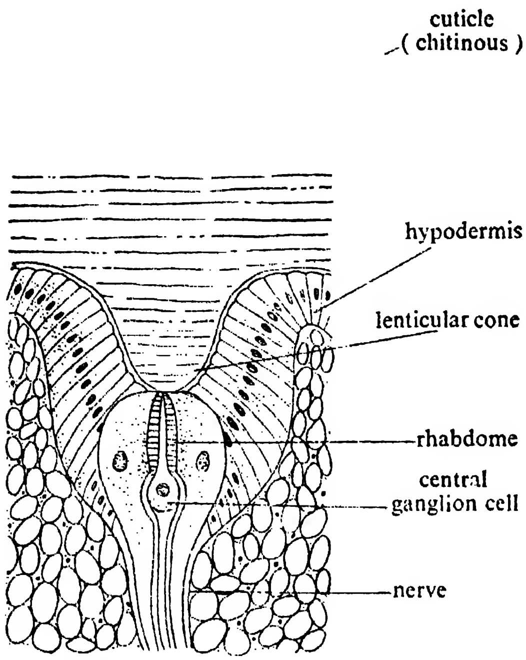


Fig. 16.102. Lateral eye of *Limulus*, sectional view.

Reproductive system

Sexes are separate and sexual dimorphism is present. The males are small in size and have hooks at the terminal ends of second and third cephalothoracic appendages.

Both the reproductive organs—*testis* and *ovary* extend within the cephalothorax and abdomen. The middle part of the gonad is placed on the dorsal side of the intestine and the anterior part is branched within the lobes of the liver. Through paired ducts, the reproductive cells pass towards genital operculum, where they open through a slightly projected aperture.

Breeding and Life history

During breeding season, both the sexes perform nuptial visit to the shore. The male fixes itself to the carapace of the female. The fertilized eggs are deposited in holes which are prepared by the female for this purpose in the region which is slightly above the high tide area. The size of the eggs varies from species to species and ranges from 1·7 to 3·5 mm in diameter.

After early development, the young horse-shoe crab comes out of the case. It has only three pairs of abdominal appendages and is without caudal spine. It resembles the trilobite in its appearance (Fig. 16.103) and is called *trilobite stage* of

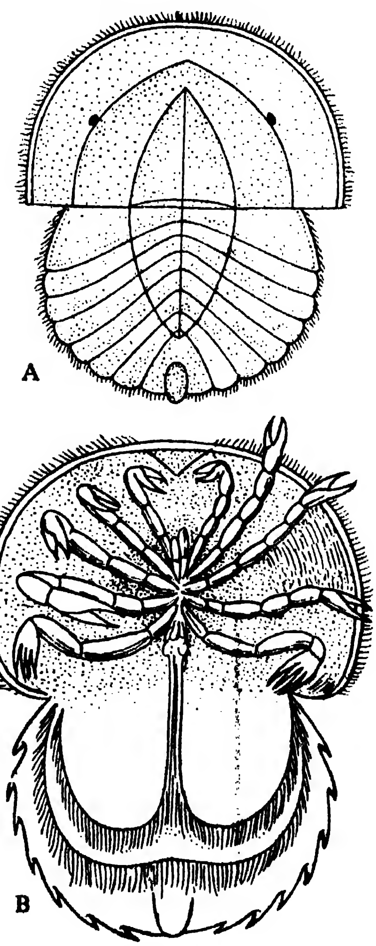


Fig. 16.103. Trilobite stage of *Limulus*. A. Dorsal view. B. Ventral view.

horse-shoe crab. It swims freely in water by its abdominal appendages. After a series of moulting it gains the features of adult *Limulus*.

Affinities

Attempts have been repeatedly made to establish relationship between horse-shoe crab and other groups of animals. Large volumes of available information may be discussed under two broad heads: (A) *Affinities with fossil forms* and (B) *Affinities with living forms*.

A. Affinities with fossil forms

1. *With Hemiaspidae* (*Fossil crustaceans*). Following are the similarities with the fossil crustaceans: (*a*) Large head is covered with dorsal shield. (*b*) A telson is present. (*c*) Two compound eyes are placed laterally. (*d*) Larval form of horse-shoe crab after first moult resembles the members of the family Hemiaspidae.

2. *With Trilobites*. Following similarities are noted between the two groups: (*i*) Cephalothorax with lateral eyes are present. (*ii*) Appendages are biramous. (*iii*) The body is longitudinally divided into three parts by two furrows. (*iv*) Presence of lateral pleural spine. (*v*) Trilobite stage in the development of *Limulus* is highly suggestive of a relationship between the two groups, so far the structural peculiarities are concerned.

But at the same time, points of dissimilarities are also evident: (*i*) Trilobites have distinct dorsal segmentation and trilobation of the body which are absent in *Limulus*. (*ii*) Absence of antennae in *Limulus*. (*iii*) Structure of abdominal appendages and genital operculum also differs.

3. *With extinct Eurypterida*. (*a*) The body in both has three regions—prosoma, mesosoma and metasoma. (*b*) In both, the cephalothoracic appendages correspond in number and position. (*c*) Appearance of limb, presence of telson, presence of median and lateral eyes are the similar features in both. The above features indicate a superficial resemblance but numerous other features of dissimilarity have excluded the possibility of any close relationship.

4. *With Chordates*. (*a*) Similarities of eyes and structure of branchial appendages lead towards the search of affinities with Ammocoetes larva. (*b*) Again, dermal skeleton, median and lateral eyes, gills and endosternum appear to be similar with the ostracoderms.

B. Affinities with living forms

Among the living forms, horse-shoe crab has close semblance with crustaceans and arachnids. Some aspects of their similarities and dissimilarities are given below:

1. *With Crustaceans*. Following are the similar features: (*i*) Aquatic habits and identical appearance of abdominal appendages appear to be similar features. (*ii*) Presence of simple median and less complicated compound eyes and (*iii*) Possession of endosternite (like *Triops*) provide strong evidences in favour of the affinity.

But the two groups differ on following points: (*i*) The respiratory organ, book gill of horse-shoe crab has no parallel in any crustaceans. (*ii*) *Nauplius* stage during development, a most distinguished feature of crustacea, is not seen in horse-shoe crab.

2. *With Arachnids*. The xiphosurids and arachnids have many common features. For this reason, both are included under the subphylum Chelicerata. But still the two groups differ. Some similarities and dissimilarities are mentioned below:

(*a*) *Similarities*

(*i*) A broad carapace covers the cephalothorax. (*ii*) Cephalothorax bears six pairs of limbs and paired median and lateral eyes. (*iii*) The caudal spine of *Limulus* resembles the post-abdominal part of scorpion. (*iv*) Presence of structures like endosternite, genital operculum and telson in both the groups. (*v*) Book gills of *Limulus* are supposed to have evolved from book lungs of scorpion. (*vi*) The suctorial pharynx, symmetrical liver, rudimentary genital glands illustrate other similar features.

(*b*) *Dissimilarities*

In spite of strong similarities with arachnids, the horse-shoe crab differs from arachnids in two important features: (*i*) absence of Malpighian tubules and (*ii*) structure of book gills.

It is evident that horse-shoe crab possesses more arthropod features and has closer relationship with Arachnida. It appears that the horse-shoe crab, together with trilobites, originated from some common arthropod ancestor but remained univer-

sally isolated. The most important feature is that the present form has undergone very little changes, if any, from their ancestors. For this reason these are called *Panchronic animals*.

Example of the Phylum Arthropoda—*SCORPION*

Scorpion belongs to the class Arachnida. It is regarded as the oldest land-living arthropod. The fossil scorpions were recovered from the beds of the earth, which are nearly 400 million years old. The most interesting feature about the scorpions is that the present forms have undergone very little changes from their fossil ancestors. Nearly 700 species of scorpions are known. The smallest scorpion is *Microbuthus pusillus* (1·2 cm) and the largest scorpion is African *Pandinus imperator* (18 cm). The other well-known scorpions are *Scorpio*, *Palamnaeus*, and *Buthus*.

Habit and Habitat

The scorpions are usually inhabitants of warm tropical regions. They are nocturnal, cryptic animals well known for their rapacious habit. They love shade and avoid heat. Some live in deserts, some in mountainous areas and several scorpions are seen in rain forests. These organisms spend the daytime within sands, crevices, holes and under stones and logs. Often the scorpions are seen within the household furniture and clothings. At night they become active and prey upon spiders, cockroaches and other insects. While walking it usually raises the body from the ground on the legs. Scorpions can live for a long time without food and water and often are seen to practise cannibalism. It can dig hole by its three anterior pairs of legs and possesses delicate sense of touch.

External structures

The body of scorpion is elongated, narrow and dorso-ventrally flattened (Fig. 16.104).

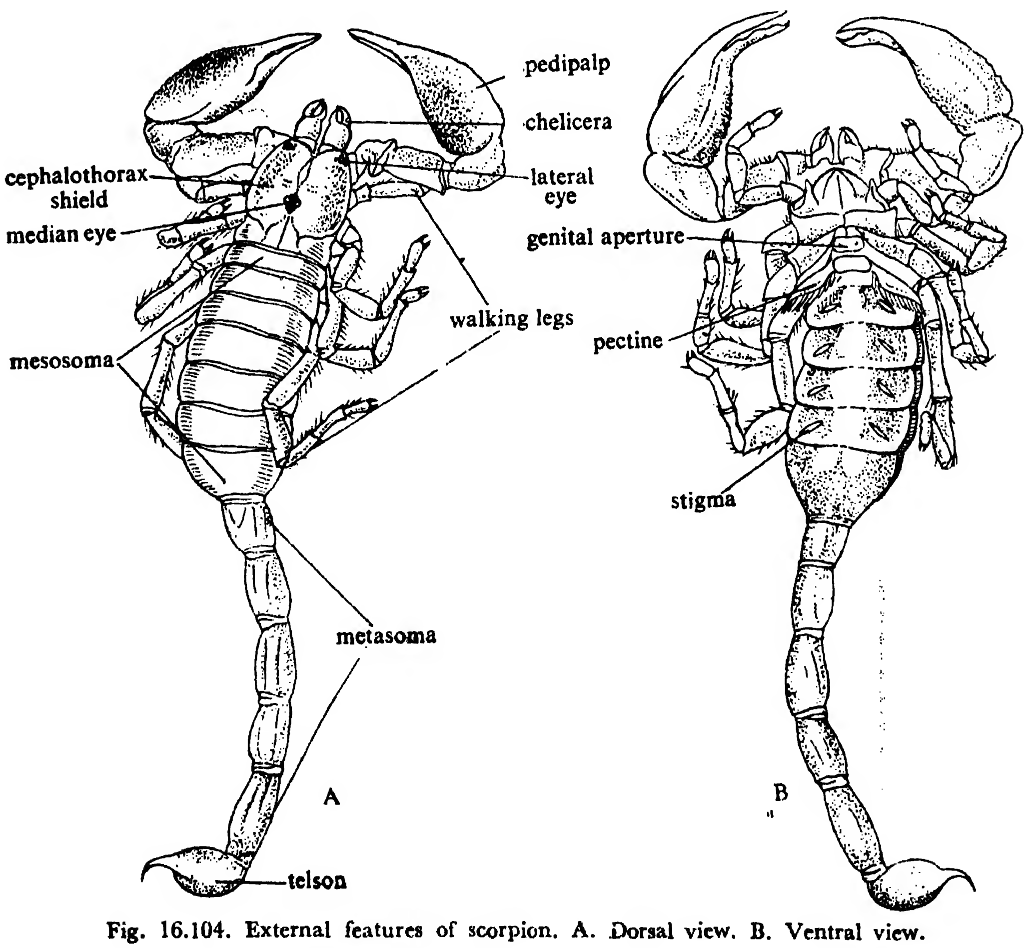


Fig. 16.104. External features of scorpion. A. Dorsal view. B. Ventral view.

The colouration of scorpion varies from yellow, orange to black and it depends upon the background of its living place. The segments are distinct and are organised to form two tagmata—*Prosoma* or *Cephalothorax* and *Opisthosoma* or *Abdomen.* Both these parts have exoskeletal coverings and several structures are present in the two regions.

PROSOMA OR CEPHALOTHORAX. As in Prawn, here too, the head and thorax have fused to form prosoma. It is enclosed dorsally by a single square *carapace* formed by the fusion of terga. Ventrally it is bounded by a single triangular plate, formed by the fusion of sternites. A median notch splits the anterior margin of the carapace into two frontal lobes. Following structures are present in the cephalothorax: (1) EYES. The dorsal side of the carapace bears a pair of *median eyes.* Several *lateral eyes* are seen along each side of the carapace. Number of lateral eyes on each side vary in different species but usually ranges from 2–5. Both the median and lateral eyes are simple eyes but differ in their construction. Some scorpions (cave-dwelling forms) have secondarily lost their eyes. (2) APPENDAGES. Six pairs of appendages on the ventral side of the prosoma include a pair of *chelicerae,* a pair of *pedipalpi* and four pairs of *walking legs* (Fig. 16.105). (*a*) *Chelicerae.* These small paired appendages are present on the anterior side of the mouth. Each one is composed of three articles. The proximal article remains beneath the carapace and the other two parts constitute a distal chela or cutting surface. When not in use, the chelicerae remain hidden beneath the carapace. (*b*) *Pedipalpi.* This second appendage is postoral and consists of following six articles from proximal to distal end—*coxa, trochanter, humerus, brachium, manus* and *movable finger.* At the proximal end, the coxa carries an anteriorly directed sharp blade-like structure called *gnathobase.* The gnathobases of the two sides work like scissors to cut the prey. At the distal end, the extension of manus forms an *immovable finger.* The inner borders of the movable and immovable fingers carry denticles and serve as chela for holding. The pedipalpi are strongly developed and are used for capturing prey, feeling the environment and to hold the partner during nuptial dance. (*c*) *Walking legs.* Each of the four pairs of walking legs is composed of seven articles and at the distal end bears a pair of sharply pointed claws. The seven parts from proximal to distal end are—*coxa, trochanter, femur, patella, tibia, pretarsus* and *tarsus.* The entire surface of each leg is beset with bristles and spurs. In each of the first and second pair of legs, the coxa is movable and has anteriorly directed gnathobases which operate during feeding. In the remaining legs, the coxae are immovable and devoid of gnathobases. The sternum, in between these two pairs of legs, bears a specific outline, which is of considerable importance in classification.

OPISTHOSOMA OR ABDOMEN. It is flat and immovably attached to the cephalothorax. The opisthosoma is divisible into two parts

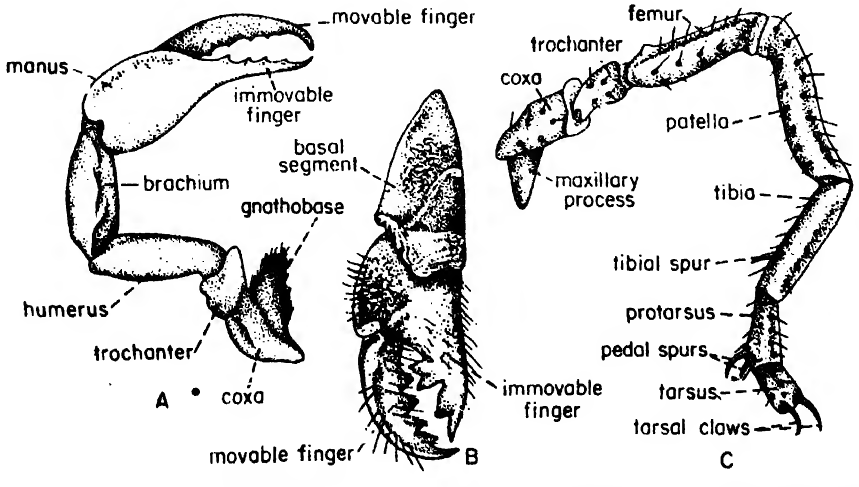


Fig. 16.105. Appendages of scorpion. A = Pedipalp, B = Chelicera, C = First walking leg.

—*mesosoma* and *metasoma*. The seven segmented mesosoma is broad at the anterior end and narrow posteriorly. The metasoma is narrow, elongated and made up of five segments which appear as jointed rings. The metasoma remains bent over the body and is movable. A soft skin separates the terga and sterna of mesosoma, but such skin is absent in metasoma. Following structures are seen in the abdomen or opisthosoma: (1) GENITAL OPERCULUM. It is present as a movable, bifid flap on the mid-ventral region of first mesosoma. It covers the reproductive opening. (2) PECTINES. These peculiar paired structures are present on the ventral side of second mesosomatic segment. Each pectine is formed of a three-segmented shaft carrying at the free posterior end a row of 4–36 movable processes like the teeth of a comb. Pectines are tactile sense organs and are probably olfactory too. Pectines are larger in males than in females. (3) STIGMATA. These are slit-like openings communicating with the inner respiratory organs called the *book lungs*. Each segment from third to sixth bears on the ventro-lateral border a pair of such stigmata. (4) POISON GLAND. The terminal segment of metasoma is bulb-like and contains a slightly curved sharply pointed poison sting. The bulb contains a pair of poison glands which open on each side below the tip. The glands are operated by a special muscle inside the bulb. The venom is used to kill the prey. It contains a paralysing neurotoxin which may affect respiratory movement specially in children and elderly people.

Integumentary system

The integumentary system forms the exoskeletal covering. As in other arthropods, here also it consists of three parts—*cuticle*, *hypodermis* and *basement membrane*.

CUTICLE. The cuticle is divisible into a very thin (0·004 mm) outermost *epicuticle* and a thick basal *procuticle*. The epicuticle does not contain chitin and is impervious to water. The procuticle contains chitin and a polysaccharide related to cellulose and is permeable to water. The procuticle may again be divided into an outer *exocuticle* and inner *endocuticle*. The cuticle is traversed by numerous canals which open through minute pores on the outer surface.

HYPODERMIS. It is composed of a monolayer of cubical epithelial cells. Some cells are peculiarly modified as tactile hairs and such hairs project out of the cuticle. The cuticle is formed by a product secreted by this hypodermal layer. Various colouration of scorpion is due to the pigment content of the hypodermal cells.

BASEMENT MEMBRANE. It is a thin noncellular layer between hypodermis and the lower muscle layers.

In various parts of the body the integument may project either entirely as a hollow process (spine, claw) or by the protrusion of cuticle alone (denticles or chela).

Endoskeleton

The coxae of the walking legs are inserted within the body and form internal skeletal structures for the attachment of muscles. These inner protrusions of coxae are called *apodemes*. In addition to apodemes, a large triangular *endosternite* and a transversely placed *diaphragm*, work as endoskeletal framework. The endosternite is present obliquely between prosoma and mesosoma and has three pairs of processes—*anterior*, *posterior* and *horizontal* for the attachment of muscles. The diaphragm is attached ventrally with the coxae of the fourth legs and dorsally to the intersegmental membrane between prosoma and the tergum of eighth segment.

Digestive system

It consists of *alimentary canal* and *digestive glands*.

ALIMENTARY CANAL. In addition to the usual three divisions—*fore gut*, *mid gut* and *hind gut*, there is a distinct *preoral cavity* in front of the fore gut.

The preoral cavity is bounded dorsally by two *chelicerae*, ventrally by the *gnathobases* of the first two pairs of legs and laterally by the *coxae* of the pedipalpi. A club-shaped *labrum* or *rostrum* hangs within the preoral cavity. Fig. 16.106 shows the transverse section of the preoral cavity of scorpion.

The sclerotised fore gut begins with a small opening called *mouth* (see Fig. 16.108A). It is placed inside the preoral cavity and near the base of the labrum. The mouth leads into a well-developed suctorial *pharynx*. The wall of pharynx is provided with numerous muscles. The

pharynx acts as a pumping organ to suck food through mouth. The pharynx continues into a narrow cuticularised *oesophagus* which runs posteriorly between tritocerebrum of brain and suboesophageal ganglion to open into the mid gut.

The epitheliated mid gut begins as *stomach*, which is small and sac-like. The stomach continues up to diaphragm and is followed by the *intestine*. The intestine is a straight tube and is distinctly divisible into a broad *mesosomal* part and a narrow *metasomal* part. The division is marked by the presence of two to four *Malpighian tubules*. From the mesosomal part of the intestine, five to six pairs of lateral *hepatic ducts* or *caeca* are given off to the digestive gland (*liver*). The metasomal intestine lying in the last metasomal segment passes into the small cuticularised hind gut. The hind gut opens to the exterior through a ventral opening called *anus*, which is located in between the last segment and poison bulb.

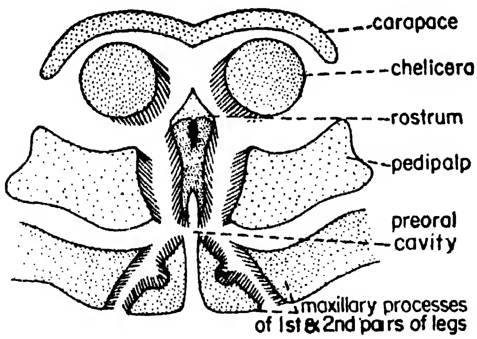


Fig. 16.106. Preoral cavity of scorpion. (Transverse section.)

DIGESTIVE GLANDS. In scorpions, two sets of digestive glands are seen. They are *salivary glands* or *stomach glands* and *gastric glands* or *liver*.

SALIVARY GLANDS. These are paired glands present within the prosoma on either side of oesophagus. From each gland a duct opens within the oesophagus. The juice is known as *saliva*.

GASTRIC GLANDS OR LIVER. This is a pair of massive, much branched glands occupying major part of the pro- and mesosomatic regions. The lateral ducts from the intestine are branched within the gastric glands to collect the juice.

MECHANISM OF NUTRITION. The scorpion is carnivorous and predator but it lives on liquid diet. The food includes various insects and spiders. As it hunts in darkness, the food is found only when it comes in contact with the pedipalps and legs. It rarely chases the prey. The chela of the pedipalps strongly grab the prey, which is then repeatedly stung. The prey is then brought beneath the preoral cavity and with the action of chelicerae are torn into fragments. These small fragments are taken within the preoral cavity. Here the food comes in contact with various enzymes like *amylases*, *lipases* and *proteases*. Only the digested part of the food is sucked inside the pharynx. Undigested part and the exoskeletal part of the prey are discarded from preoral cavity. From intestine, food enters within the lateral ducts, where it comes in contact with juices from the liver for complete digestion. Residual matters are finally ejected through the anus.

Respiratory system

Respiratory organs are known as *book lungs*. Four pairs of such organs, one pair in each of the third, fourth, fifth and sixth mesosomatic segments, are housed within special chambers called *pulmonary sacs*. In embryos, the book lungs originate externally from the ectoderm but in adult they are tucked in and are finally lodged within the inner pulmonary sacs. Each book lung consists of nearly 140 vertically folded leaves or *lamellae* (Fig. 16.107) with chitinous lining. These are the respiratory surfaces. The edges of the leaves remain attached with the wall of the pulmonary sac by one

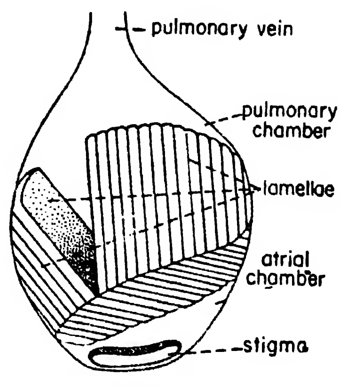


Fig. 16.107. Showing the structural organisation of a book lung of scorpion.

end, while the other end remains free. Each lamella contains a hollow cavity,

through which blood flows. The venous blood comes from ventral sinus and aerated blood returns through pulmonary vein. In between two lamellae, lies a thin air space. All these intra-lamellar air spaces communicate with a central chamber called *atrium* or *atrial chamber* which opens to the exterior by spiracle.

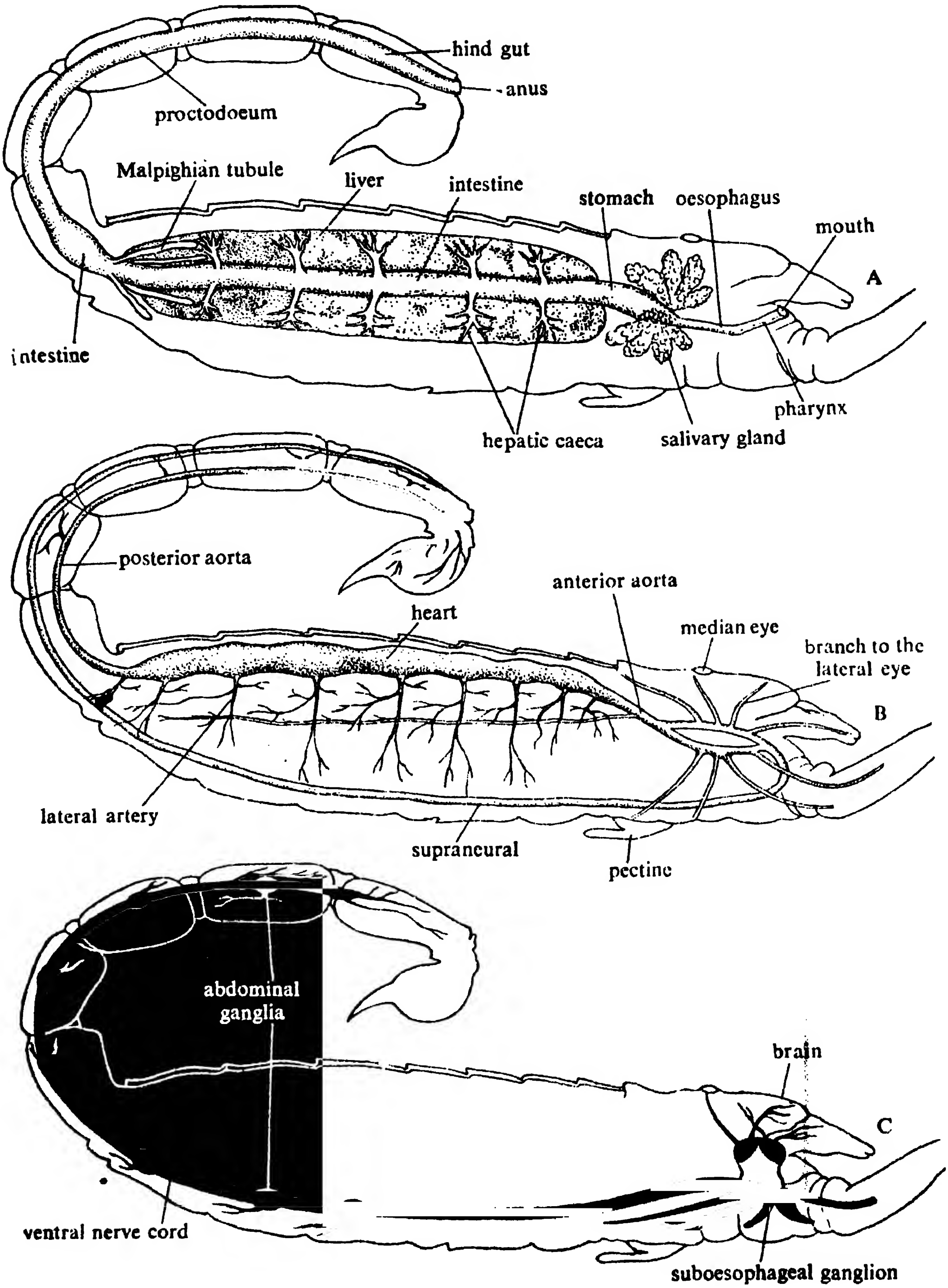


Fig. 16.108. Internal structures of scorpion. A. Alimentary system (lateral view). B. Heart and arterial system (lateral view). C. Nervous system (lateral view).

Mechanism of respiration. The working of special set of muscles called dorso-ventral muscles and atrial muscles cause the contraction and relaxation of book lungs. When the book lungs are relaxed air rushes inside through stigmata to the atrial chamber and interlamellar spaces. The diffusion of gases occurs in the interlamellar spaces. When the muscles contract, the book lungs expel the air out.

Circulatory system

The circulatory system of scorpion includes—*blood, heart, arteries, veins* and *sinuses*.

Blood. Like that of prawn, blood is bluish in colour due to the presence of a copper containing respiratory pigment called haemocyanin dissolved in the plasma. In this liquid are suspended large and oval leucocyte like corpuscles.

Heart. Elongated and tubular heart is present in mid-dorsal region and extends between eighth and fourteenth segments. The heart consists of seven chambers—one in each of these segments (Fig. 16.108B). Heart is placed within a haemocoelomic space called *pericardium*. Each chamber is in communication with the pericardial cavity by means of a pair of valve-like openings, *ostia*.

Blood vessels. From each chamber of the heart arises a pair of lateral arteries in each segment. At the anterior end, heart sends a *truncus arteriosus* or *anterior aorta*, which sends a pair of branches to the alimentary canal and then bifurcates to form two vessels to supply different parts of the prosoma. The two branches towards the alimentary canal encircle the digestive tube and unite on its ventral side. After union, it runs posteriorly above the ventral nerve cord and becomes *supraneural artery*. From the posterior end of the heart originates a branch known as *dorsal aorta* or *posterior aorta* which runs along the mid-dorsal line to the posteriormost tip of the body. It sends branches to the different parts of the posterior region.

Five large *sinuses*, the *pericardial*, the *dorsal*, the *ventral* and the two *laterals* are present in scorpion for collecting blood. The dorsal sinus is placed above the pericardial sinus. The pericardial sinus receives oxygenated blood from the book lungs by several pairs of *pulmonary veins*—one pair from each segment. The upper wall of the *ventral sinus* is connected with the floor of the *dorsal sinus* by means of seven pairs of *veno-pericardial muscles*. The contraction of heart drives blood to the different parts of the body through the arteries. The arteries finally open into the haemocoelomic spaces at the different parts of the body. The deoxygenated blood from different parts of the body is collected first within lacunae and then into dorsal and lateral sinuses. Finally, the deoxygenated blood comes to the ventral sinus. From ventral sinus, blood is sent to the book lungs for oxidation. The oxygenated blood from each book lung returns to the pericardium through a pulmonary vein. When the heart expands, the blood from pericardial space enters within the cavity of the heart through ostia.

Diagrammatic representation of course of blood circulation in Scorpion :

Arteries ← Heart ← Ostia ← Pericardium
↓ ↑
Blood lacunae among viscera Pulmonary vein
↓ ↑
Dorsal, lateral and perivisceral sinus — Ventral sinus → Book lungs

Excretory system

Several sets of excretory organs are seen in scorpion: (*a*) *Malpighian tubules*, (*b*) *Coxal glands*, (*c*) *Large nephrocytes* and (*d*) *Lymph tissue organ*.

(*a*) Malpighian tubules. Two to four Malpighian tubules are present near the beginning of the metasomatic part of the intestine. One end of these thread-like tubes opens within the intestine. The other end is blind and removes excretory material as guanin and uric acid. Malpighian tubules in scorpion have different embryonic origin and thus are not homologous to those of insects. One Malpighian tubule enters within the salivary gland and the others penetrate within the lobes of the liver.

(*b*) Coxal gland. These paired glands are present in the prosomatic region, one on each side and near the base of third walking leg. Internally, each gland has three parts—*end sac*, *labyrinth* and *bladder*. From bladder, a slender duct arises and opens through a minute aperture, present at the base of third walking leg. The coxal glands usually eliminate uric acid.

(*c*) Large nephrocytes and (*d*) Lymph tissue organ. These specialised structures are present in the wall of the mesosoma and are believed to be both phagocytic and excretory in functions. The lymph tissue organ is absent in the family Buthidae.

Nervous system

The nervous system is built up on typical arthropod plan and consists of *central nervous system*, *peripheral nervous system* and *sense organs*.

Central nervous system. The central nervous system does not exhibit extreme condensation which is the peculiarity of other arachnids. It consists of a pair of small *supraoesophageal ganglia* or *brain* situated in the prosoma and in between the median eyes (Figs. 16.108C & 16.109). In each side, the brain sends a *circumoesophageal connective*. It encircles the oesophagus and unites with a ventromedian *suboesophageal ganglion*. The suboesophageal ganglion is formed by the fusion of ganglia of second to eleventh segments. A double *ventral nerve cord* arises from the suboesophageal ganglion and runs posteriorly up to the fourth segment of the metasoma. In the mesosomal part, the nerve cord is narrow and round in cross-section but in the metasomal part it is tape-like and flat. The nerve cord *bears* three ganglia in the mesosomal part (*Pre abdominal ganglia*) and four in the metasoma (*Postabdominal ganglia*). The last metasomal ganglion is formed by the fusion of ganglia belonging to eighteenth and nineteenth segments.

Peripheral nervous system. From brain arises a pair of *optic nerves* to supply median and lateral eyes. Numerous slender *nerves* also originate from brain to innervate the preoral cavity, pharynx and oesophagus. From suboesophageal ganglion six pairs of *lateral nerves* arise to supply the prosomal appendages and two to four pairs of *vagus nerves* to supply the pectines, genital operculum and first two pairs of book lungs in the mesosomal part of the abdomen. From each ganglion on the ventral nerve cord, paired nerves are given out to innervate various structures in the corresponding segments. The two pairs of posterior or metasomal book lungs are supplied by nerves from the first two metasomal ganglia.

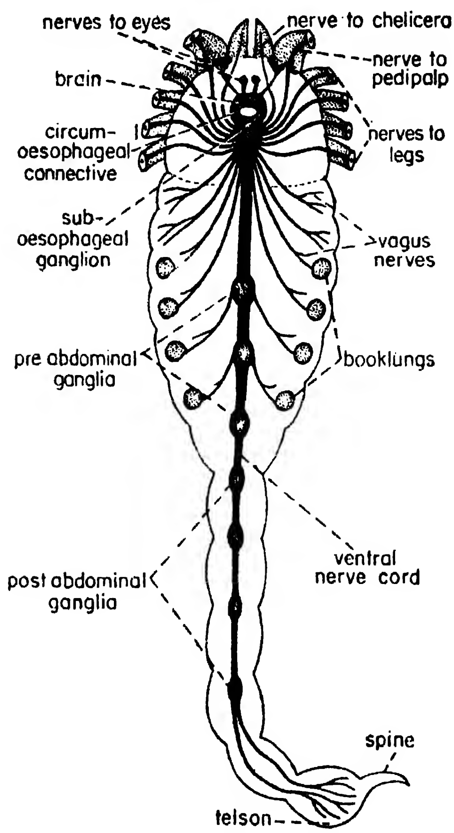


Fig. 16.109. Nervous system of scorpion. (Dorsal view.)

Sense organs. The sense organs of scorpion include *sensory setae*, *trichobothria*, *slit sense organs*, *pectines* and *eyes*.

Sensory setae. These are fine hair-like structures with supply of nerve fibres. Such hairs are sparsed all over the cuticle.

Trichobothria. Each trichobothrium is composed of a seta which is inserted within a cuticularised flask-shaped *bothrium* through the middle of a circular outer membrane. Within the bothrium the seta bends and gradually tapers within a fluid-filled cylinder to become a helmet-like structure. This helmet-like tip of the seta is supplied by branches of nerve fibres.

Each trichobothrium is capable of moving the seta in one direction only and is sensitive to air current. There are about 66-68 trichobothria on each chela and are arranged in different planes.

SLIT SENSE ORGANS. These sense organs are distributed all over the body, but are usually crowded over the appendages. Each slit sense organ consists of an outer slit with an epicuticular membranous covering. Each slit measures nearly 0·005–0·16 mm in length and 0·002-0·003 mm in breadth. The slit leads into a crevice which penetrates within the procuticle as a membrane-lined tube. Numerous fine nerve fibres supply the inner wall of the tube. The sense organ chiefly reacts to the movement of the joint and also works as vibration receptor.

PECTINES. The structure of pectine has already been described. These are tactile sense organs and play important role in food capture. The males use it for the detection of suitable surface to deposit spermatophores and the females use it for collecting spermatophores.

EYES. Both the median and lateral eyes are simple and are provided with lens. The median eyes are *diplostichus* type; here the hypodermal cells in the lower part of the lens are transformed into a *vitreous body* and the rhabdome of the retinulae is made up of five rhabdomeres. The lateral eyes are *monostichus* type. Here vitreous body is absent and the structure of rhabdome is irregular. The function of both the median and lateral eyes is not understood. Being a nocturnal animal it depends very little on eyes. It shows negative phototropism but is often attracted by strong glare of light, i.e. campfire, lantern, etc.

Reproductive system

Scorpions have separate sexes but the sexual differences are not distinct. The males are marked with narrower abdomen and powerful pedipalpi than females. The pectines of male contain more teeth than females.

MALE REPRODUCTIVE SYSTEM. The male reproductive organs or *testes* are paired, laterally placed tubular organs, present in the third to sixth segments of the preabdomen. These are connected to each other by transverse tubes (Fig. 16.110A). Thread-like sperm cells are collected from the testes by a pair of *vasa deferentia*. Each vas deferens begins from the outer border of the testis and runs anteriorly along the lateral wall of the body cavity. Each vas deferens opens within a *genital chamber*. Immediately before opening into the genital chamber, the vas deferens receives *accessory gland* and a broad *seminal vesicle*. Posteriorly, the genital chamber is drawn into a bag-like *paraxial organ*, which contains a spiny and grooved chitinous rod called *flagellum*. The two genital chambers unite to form a *common genital chamber*, which opens to the exterior through a *genital pore* beneath the genital operculum in the first mesosomal segment. The sperms remain stored in the seminal vesicle. The paraxial organ produces a structure called *spermatophore*. During copulation, the spermatophore enters the *genital chamber* and receives the sperm cells from the seminal vesicle. The accessory glands produce a kind of cementing material to constitute the adhesive stalk of the spermatophore and also for sealing the two halves of the spermatophore. A spermatophore is 5 mm in length and is deposited on a suitable substratum at 45° angle (Fig. 16.110B). Each spermatophore consists of a lower *stem* and a *base* for attachment and the stem bears a *sperm container* and an *ejection apparatus*. With the ejecting apparatus is attached a dagger-shaped *lever*.

FEMALE REPRODUCTIVE SYSTEM. The female reproductive organ or *ovary* is single and it includes three elongated tubes or *ovarioles*, with numerous tubular interconnections (Fig. 16.110C). It is present in the same position of preabdomen as that of testes in the male. Within the inner lining of the tubular ovariole, the eggs or ova are produced but are not released before fertilization. Within the ovary the eggs grow on bud-like processes, called *follicles* which may be of varied shapes in different scorpions. Two oviducts, one from each lateral ovarioles, run anteriorly and unite to form a *common oviduct* or *genital chamber*. The chamber opens to the exterior through small opening beneath the *genital operculum*.

MECHANISM OF REPRODUCTION. The scorpion is noted for its peculiar courtship dances (Fig. 16.110 a–c). The male, while approaching a female flickers the post-abdomen vertically. When the female responds by doing similar movement, the male grabs the female's pedipalps with its

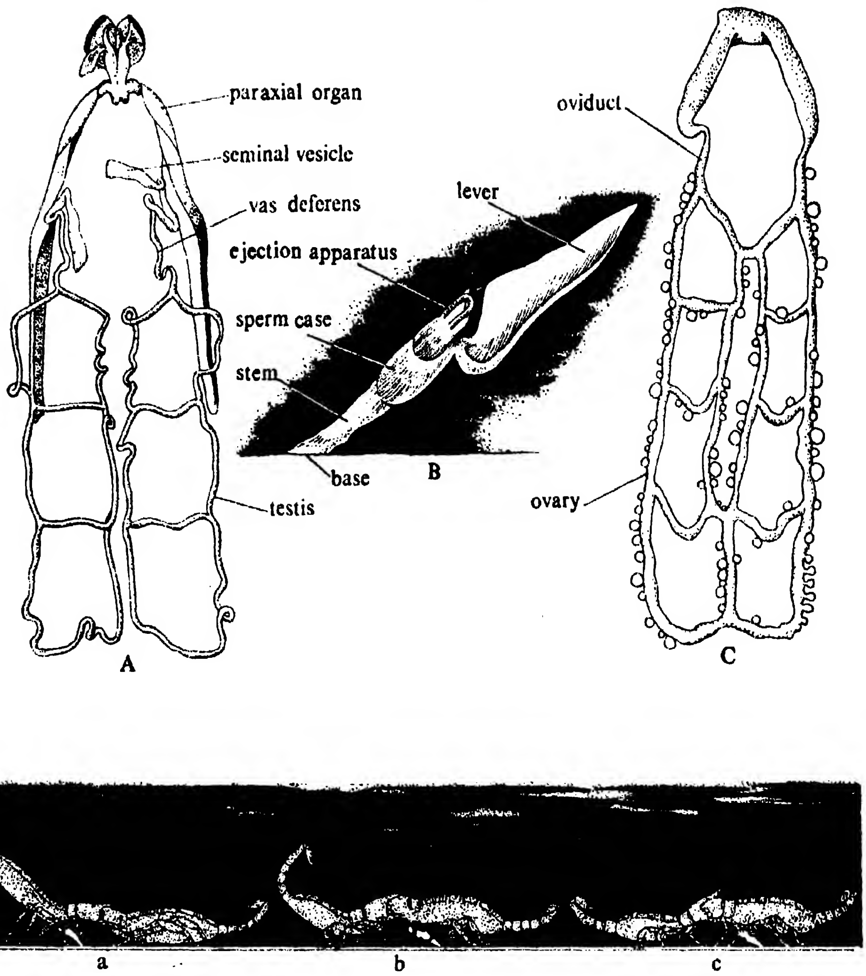


Fig. 16.110. A. Male reproductive system of scorpion. B. Spermatophore of scorpion. C. Female reproductive system of scorpion. a-c. Courtship of scorpions. a. Male holds the female and deposits the spermatophore. b. Male draws the female to spermatophore. c. Female lifts up the spermatophore (after Kaestner).

own and moves backward in a straight line. This movement may continue for $\frac{1}{2}$–2 hrs. At this time, the male, with the help of its anterior pairs of legs, touches the pectines and genital opercula of the female. The pectines of male frequently touch the surface and its posterior legs perform a scratching movement on the surface. Formerly, it was thought that the nuptial dance of scorpion is to excite female. But now its correct meaning is understood. This dance is intended only to find a suitable surface for depositing the spermatophore. When the spermatophore is deposited, the male drags the female over it. When the genital operculum of female touches the lever of spermatophore, the ejecting apparatus shoots the sperm within the female genital tract. The pectines of male play important role in finding the suitable surface. It has been shown experimentally that a male scorpion with excised pectines perform routine nuptial dance with the female but it never deposits the spermatophores.

Development. The scorpions may be viviparous or ovoviviparous, depending upon the content of yolk in the egg. In the viviparous forms the yolk content is poor. Such fertilized eggs grow on the follicles of the ovary. The follicle acts as 'placenta' and provides nutrition to the embryo. In ovoviviparous forms the yolk content is high and in them the fertilized eggs drop within the tube of the ovary and develop there. In the embryo, seven pairs of appen-

dages appear in the mesosoma but the appendages in the fourth to seventh segments are tucked in to form the book lungs. Newly born scorpion resembles its mother and immediately after birth climbs on her back. It remains there for 40–63 days and undergoes three moults. It then starts independent life but maturity takes 1–5 years to complete and during that time the scorpion moults seven times.

EXAMPLE OF THE PHYLUM ARTHROPODA—*SPIDER*

Habit and Habitat

The spiders are of various types (30,000 species) and are seen to be adapted to the various environmental conditions. Broadly speaking, the spiders may be grouped into—*wanderers* (do not spin) and *spinners* (web some form of net). Most of them capture insects and some forms are known to capture even birds. The examples of common spiders are *Nephila* (garden spider), *Lycosa*, *Salticus* (both are hunting spiders) and *Latrodectus* (Black widow). The largest spider *Theraphosa leblondi* of Guyana may grow up to 9 cm in length.

External structures

The body is divided into two regions—*cephalothorax* or *prosoma* and *abdomen* or *opisthosoma* (Fig. 16.111). The outer part is covered by a hard *exoskeleton* which exhibits diverse striations and colourations in different types.

CEPHALOTHORAX. The cephalothorax is covered dorsally by a uniform *carapace* and ventrally by a broad, strongly built unsegmented *sternum*. The cephalic or head part contains *eyes*, *appendages* and *mouth*.

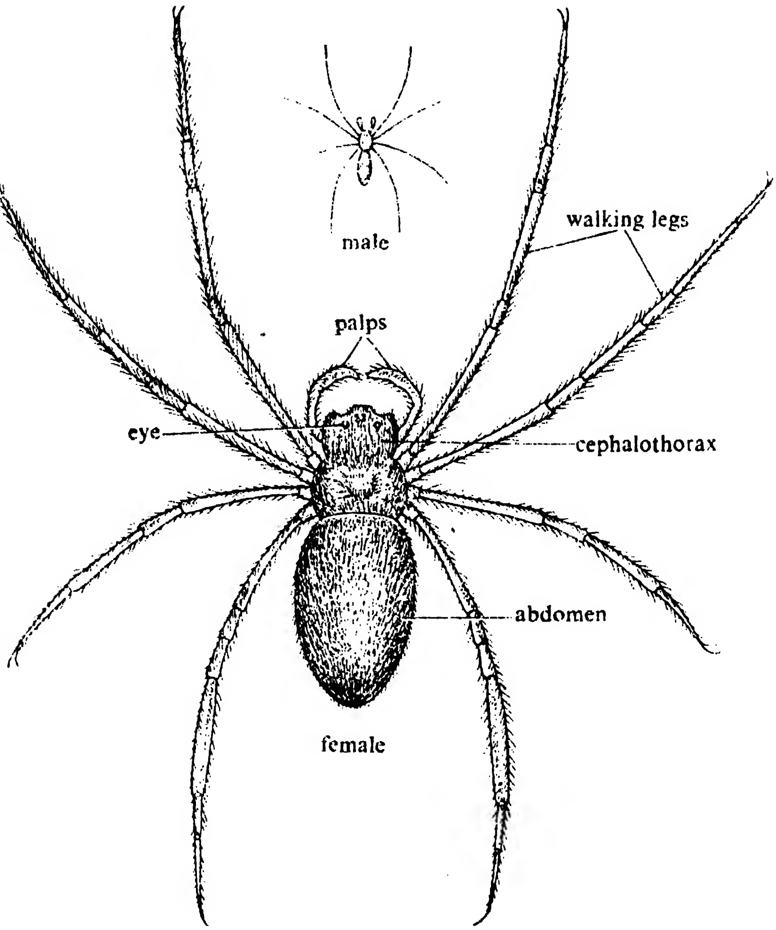


Fig. 16.111. External features of spiders.

EYES. The *eyes* are simple but distinctly

developed. Eyes are never more than eight and are placed in two transverse rows. Each row consists of two median eyes and two lateral eyes are placed one on each side of the median eyes.

Appendages. Two pairs of *cephalic appendages* are known as *chelicerae* and *pedipalpi*. The first pair, i.e. chelicerae is placed anteriorly on the dorsal side of the mouth (Fig. 16.112 A, B). Each is made up of two parts

Mouth. Mouth is bounded by two lips —*upper lip* and *lower lip*. The upper lip, also known as *rostrum*, is present between chelicerae and pedipalpi and its inner side constitutes the upper part of the *epipharynx*. The lower lip or *labium* forms the ventral part of the mouth and help in sucking liquid food.

Both the tergum and sternum of the thorax have grooves along which the body

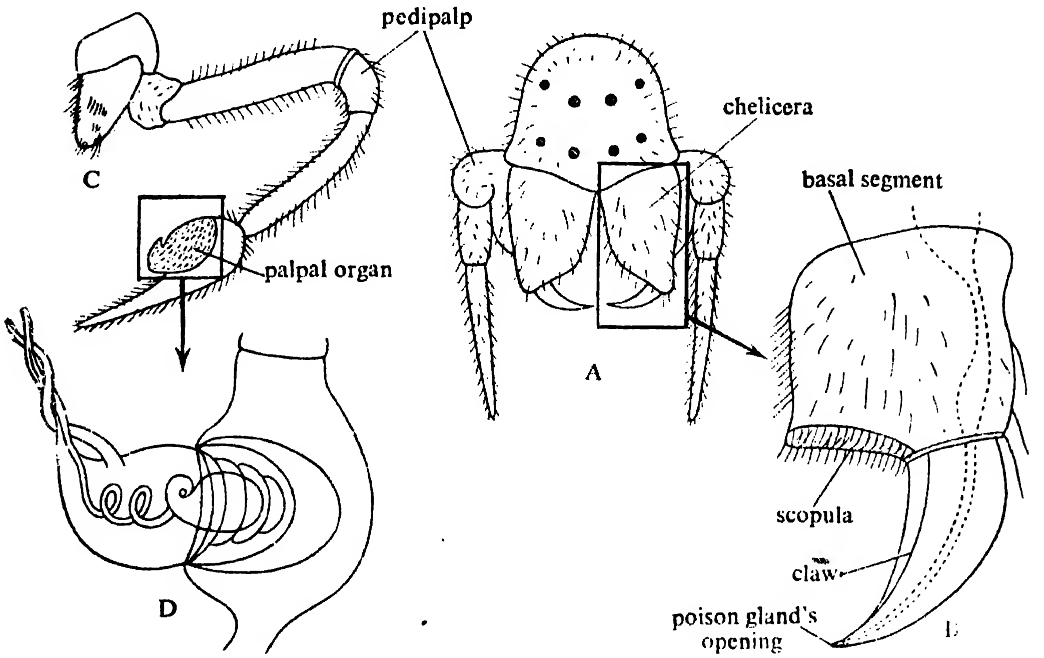


Fig. 16.112. Diagrammatic view of cephalic appendages of spider. A. Magnified view of head to show the position of chelicerae. B. Enlarged view of a chelicera. C. Magnified view of a pedipalp. D. Enlarged structure of palpal organ or intromittent organ.

—broad basal segment and terminal clawed part. Within each chelicera and often extended within the cephalothorax, lies a cylindrical *poison gland*. The poison duct opens at the convex side of the claw. The chelicerae may be modified in different groups according to the way of life. The pedipalpi may be leg-like, antenna-like or reduced. In some, together with chelicerae it forms a *preoral chamber*. The pedipalp consists of six segments; the basal one is called *coxa* and this is followed by *trochanter*, *femur*, *patella*, *tibia* and *tarsus*. The tarsus consists of a single segment and *metatarsus* is absent. An intromittent organ or palpal organ is present at the base of the distal article of each pedipalp (Fig. 16.112 C, D).

muscles remain attached. Four pairs of *walking legs* are present in the thoracic region. Each leg is made up of the following seven segments—*coxa*, *trochanter*, *femur*, *patella*, *tibia*, *metatarsus* and *tarsus*. The tarsus is provided with a pair of comb-like claws.

Abdomen. It is connected to the cephalothorax by a thin *pedicel*. The pedicel remains covered under the abdomen. The anterior part of the abdomen is concave and is called *epigastrum*. It is separated from the rest by an *epigastric furrow*. The abdomen contains the following structures: (1) **Stigma** or **Spiracle**. Four in number and communicate with the respiratory organs. The position of the spiracle varies. In some, it may open posteriorly on the

ventral side of the segments VIII and IX. In others, posterior spiracles may be at the posterior end of the abdominal segments. (2) GENITAL APERTURES. In both the sexes, the reproductive openings are present at

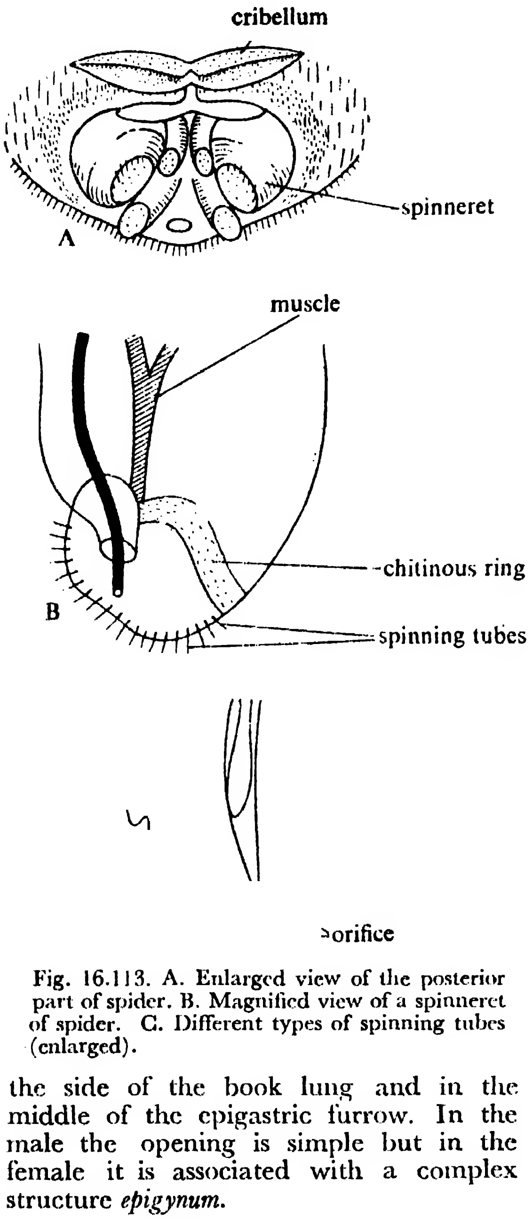


Fig. 16.113. A. Enlarged view of the posterior part of spider. B. Magnified view of a spinneret of spider. C. Different types of spinning tubes (enlarged).

the side of the book lung and in the middle of the epigastric furrow. In the male the opening is simple but in the female it is associated with a complex structure *epigynum*.

SILK GLAND AND SPINNERETS

The silk glands are fairly large and present in the 10th to 11th segments. Each gland is lined by a single layer of cells. These cells produce silk, which pass through *spinning tubes*. The silk glands vary in different species. In orb spiders, there are six kinds of silk glands, each liberating a special kind of silk. The silk of spider is highly elastic and has the maximum tensile strength. The silk is composed of *fibroin*, a kind of protein. Each thread is either flat or cylindrical and its diameter varies. The *spinnerets* are specialised structures for spinning silk (Fig. 16.113). The number of spinnerets vary in different spiders. These are present on the posterior part of the abdomen. These are called fore, mid and hind spinnerets. Each spinneret has a stout base, but the tip is membranous and covered by barbs and hairs. Over the surface of the spinning field there are many spinning tubes which are of different shapes. Special structures called the *cribellum* (accessory spinning organ) and *calamistrum* (brush-like hairs on the metatarsus of the 4th leg) are often present to work with the spinnerets.

Digestive system

The alimentary canal is divisible into (*a*) *fore gut*, (*b*) *mid gut* and (*c*) *hind gut* (Fig. 16.114A). The fore and hind guts are lined by cuticle and the mid gut has epithelial lining.

The fore gut consists of following parts: (*i*) *mouth*, (*ii*) *pharynx*, (*iii*) *oesophagus* and (*iv*) *stomach*. The lateral walls of the mouth parts are provided with rows of minute hairs which filter out small particles. The *pharynx* is broad and flat and leads to a narrow *oesophagus*. The oesophagus has a small diverticulum which bears *chemoreceptors* to determine the taste of the food. The *stomach* has folded wall with thick chitinous lining. The stomach possesses two sets of powerful muscles, one set is responsible for contraction of the stomach and another set dilates it.

The mid gut sends *diverticula* or *caeca* within the cephalothorax and it sends branches towards each leg. The abdomen is also filled up with several *diverticula* from mid gut. These are called liver or *digestive diverticula*. Each gland or diverticulum contains two types of cells: (*i*) *secretory* and (*ii*) *absorptive*. An albuminous substance given out from the secretory cells mixes up with the food. These are then taken by specialised cells, within which the food is broken down into simpler forms. The absorptive cells collect indiffusable and insoluble products. Such filled up cells are thrown out during egestion.

The hind gut is short and receives *Malpighian tubules*. A *cloacal diverticulum* or *stercoral pocket* is present posteriorly, where faeces are stored temporarily before being ejected through the anus. The opening and closure of the anus are controlled by sphincter muscles.

tracheal trunks called *sieve tracheae*, give rise to several small tracheae. In all spiders, the tracheal system is well-developed in young stage. In early stage of development the tracheal spiracles are placed posteriorly which subsequently shift upwards.

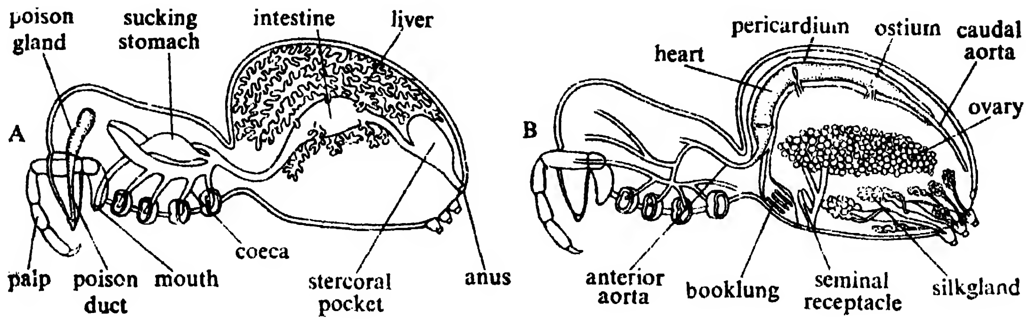


Fig. 16.114. Internal structures of a spider. A. Showing alimentary system and position gland. B. Showing respiratory, circulatory, reproductive (female) structures and silk apparatus.

All spiders are carnivorous. The food ranges from flies to small birds. Most spiders spin webs for the capture of prey. The captured prey is first paralysed by the secretion of poison gland. The salivary glands present at the underside of the lip produce proteolytic enzymes, which are either poured or injected within the body of the prey. When the prey is softened, the spider sucks out the juice by the contractile action of the pharynx and stomach. Large particles are not allowed to enter into the gut by the setae and spines of the labrum. The transversely arranged ribs on the anterior wall of the pharynx also act as filter to remove particles. Further digestion and absorption take place within the mid gut diverticula. Faeces pass into the hind gut and before final egestion remain temporarily stored within the stercoral pocket.

Respiratory system

Two types of respiratory organs are seen —*book lung* and *tube trachea*. Two pairs of book lungs are usually present in spider. The structure of the book lung is same as that of scorpion. Inside each book lung, sclerotised lamellae are arranged like the pages of a book. The book lungs open through *stigmata* or *spiracles*, one on each side of the genital pore and on the anterior and ventral surface of the abdomen. The tracheal system may be of varied types. In some (e.g. *Dysderidae*), a pair of large

Circulatory system

The heart is abdominal (Fig. 16.114B) and placed within distinct pericardium. In forms having less developed tracheal system, the heart is large and arterial network is well-developed. Two to five pairs of ostia open within it. The heart sends (*i*) an *anterior artery*, (*ii*) paired *lateral arteries* depending upon the size of the heart and (*iii*) a *posterior artery* as extension of the heart.

Excretory system

The excretion in spider is carried out by (*a*) *absorptive cells*, (*b*) *guanine cells*, (*c*) *nephrocytes*, (*d*) *Malpighian tubules* and (*e*) *coxal glands*.

(*a*) *Absorptive cells* are present in the intestinal wall. Some of these cells collect egestable substances. These cells either pour their contents inside the lumen of the gut or the entire cell drops into lumen and are then removed from the body. (*b*) *Guanine cells* are also distributed near the inner layer of intestine. These cells collect excretory products which are called *guanates* and release them within the lumen of the gut in liquid form. After coming to the cloacal pocket, these liquid guanates mix up with some acids produced by the hind gut and become crystalline. (*c*) *Nephrocytes*. These specialised cells are present in the cephalothorax and are supposed to have some excretory functions. (*d*) *Malpighian tubules*. These are

the chief excretory organs and are represented by two sets of pseudociliated dichotomously branched tubules which arise from the cloacal pocket. A rythm of muscular contraction which begins from the tip of the tubule drives the excretory products downwards. Each tubule is a syncitium and produces a slightly acid secretion. Malpighian tubules remain restricted to the abdomen. (*e*) *Coxal glands*. These glands are either one or two pairs and are confined to the prosoma. Each gland is a sac-like structure and a short excretory duct from this sac runs up to the posterior end of walking legs. Their openings are placed at the posterior end of first and third walking legs. Where one pair of coxal glands is present, it opens through the first walking legs.

Nervous system

The nervous system exhibits highest degree of condensation. In the cephalothorax, the *brain* is represented by *supraoesophageal ganglion*. It is connected with a large ventral *suboesophageal ganglion*, which is formed by the union of all the posterior ganglia. The sense organs include *sensory setae*, *trichobothria*, *slit sense organs* and *eyes*. The *sensory setae* are hair-like structures and remain scattered all over the surface, specially on legs. The elongated *trichobothria*, resembling those of scorpion, are present on the pedipalpi. The *slit sense organs*, like those of scorpion, remain distributed over the integument. These are responsible for detecting vibration and sensing mechanical stresses. *Eyes* are simple but well developed. They are never more than eight and are arranged in two transverse rows. Each row consists of a pair of median eyes and a pair of lateral eyes on the sides. In median eyes, the rhabdomes face the lens but in other eyes the rhabdomes are moved inwards.

Reproductive system

The sexual dimorphism is the characteristic of the spiders. The males are much smaller than the females.

In males, a pair of *testes* are present. Each testis includes several tubes which are arranged in parallel rows along the ventral margin of the abdomen. From each testis arises a *genital duct* which opens within a common median *atrium*. The male genital apertures are present in the abdomen near the stigmata. The pedipalp carries a *palpal organ* or *intromittent organ* (a structure used to transfer the sperm within female body).

In females, the reproductive organs are paired *ovaries* (Fig. 16.114B). The ovaries unite posteriorly to form a *common oviduct* which enlarges as an *atrium* or *uterus*. A pair of *seminal receptacles* open within the atrium. It opens to the exterior through an aperture called *vagina*, which is located at the epigastric furrow. The female genitalis is covered in most cases by a complex structure called *epigynum*. It possesses a *guiding groove* and functions to guide the passage of male intromittent organ. On the side of each oviduct a *spermatheca* is present and is connected with *epigynum groove*.

Breeding and Life history

The reproductive behavior of spider is interesting and it varies widely. Usually, a mature male spins a kind of web, called *sperm web*. It deposits a drop of sperm on it. After a few minutes, the male immerses its intromittent organ repeatedly in that drop of sperm. Such dipping continues for one and half hour. When the organ is filled up, the sperm web is destroyed. The male then looks for a mature female. The female waits in her web and the male detects her with the help of its chemoreceptors. Various types of courtship behaviours follow in different spiders. Finally, the male introduces either one or both the palpi within the female gonopore. The sperms are deposited in the seminal receptacles of the female. The fertilization takes place shortly before the laying of eggs. Some species of spider exhibit care of the eggs and youngs. A newly hatched spider moults 5–12 times before becoming an adult. Immediately before moulting the thickness of the exoskeleton reduces to one-third, due to prior enzymatic digestion of the endocuticular part. The spider takes no food immediately before or immediately after moulting.

Example of the Phylum Arthropoda—*PERIPATUS*

Peripatus belongs to the group *Onychophora*. Formerly the onychophora was treated as a class and it was placed as an appendix to the phylum Arthropoda, but recently it has been given the status of a separate phylum. In the present text,

Peripatus is described as an example of the phylum Arthropoda. Nearly 70 species are included within the class and the largest species is *Peripatopsis torquatus*, having a length of 15 cm. Peripatus is seen in temperate and tropical areas of Southern Hemisphere, north of Caribbean, Central Mexico, S. E. Asiatic islands, India and the regions of Africa which are south of equator. The following genera are found in different parts of the world: (*i*) *Peripatopsis* (America and Africa), (*ii*) *Eoperipatus* (Indo-Malay), (*iii*) *Peripatoides* (Australia), (*iv*) *Ooperipatus* (Australia), (*v*) *Opisthopatus* (Chili and South Africa), (*vi*) *Paraperipatus* (New Britain), (*vii*) *Peripatopsis* (Central America) and (*viii*) *Typhloperipatus* (Eastern Himalayas).

Habit and Habitat

These are terrestrial animals and are denizens of humid localities. Its favourite residing places are within litter, underneath of logs or stones in forests or in areas near water. It is insectivorous and the food is captured by spurting mucus from the adhesive glands of *oral papillae*. Such spurting may go up to 30–50 cm. On the body of the victim the secretion forms a sticky web but on the skin of Peripatus it turns into droplets.

External structures

The body of Peripatus is caterpillar-like (Fig. 16.115). It is soft, elongated and roughly cylindrical. The segmentation is indistinct and marked only by the presence of paired appendages. Numerous superficial lines or annuli mark the body, but such annuli do not correspond to segmentation. The colouration usually varies from dark gray to brown. But red, blue and green colourations are also marked.

The entire body may be divided into (*a*) an indistinctly set off *head* and (*b*) an elongated *trunk*.

Head. The head of Peripatus (Fig. 16.116A) consists of following structures: (1) Prostomium or acron. It is the anteriormost part of the head. It bears a pair of *eyes* but paired *appendages* are absent. (2) Antennae. One pair of antennae represent the first pair of appendages. The entire surface of each antenna is surrounded by numerous spiny rings. The slightly narrow anterior end of each antenna is enclosed by a sheath of spiny tissue.

(3) Mandibles. A pair of mandibles constitute the second paired appendages. These are present deep inside the mouth cavity. Each mandible is small, muscular, stumpy and provided at its free end with a pair of sharp cutting blades. The base of the mandible is extended posteriorly up to the second leg-bearing segment. A chitinous rod, *apodeme* is secreted from the base of the mandible and acts as site for the attachment of muscles. The *salivary duct* from *salivary gland* opens behind the mandible. (4) Oral papillae. Third paired appendage is a pair of oral papillae. Each papilla is situated at the sides of the head. The terminal end of the papilla serves as the exit of a special kind of gland, called *slime gland*. *Mouth* is present immediately behind the oral papillae and on the ventral side.

Trunk. The trunk is devoid of exoskeletal coverings and its skin is drawn into a number of ridges along which wart-like papillae are placed. The trunk possesses 14–43 pairs of *legs*. Legs are all alike and are placed at regular intervals. Each leg is hollow and cone-shaped but appears as if squared off at the tip (Fig.

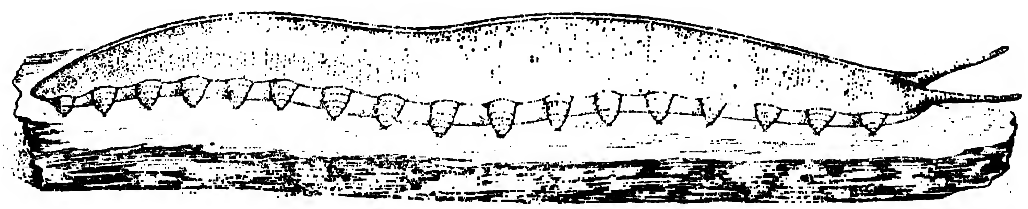


Fig. 16.115. External features of *Peripatopsis* (after Balfour).

N.B. Peripatus is a common name. Earlier all the species under class Onychophora were grouped under a single genus *Peripatus*. This practice has recently been rejected. Different species have now been put under twelve genera.

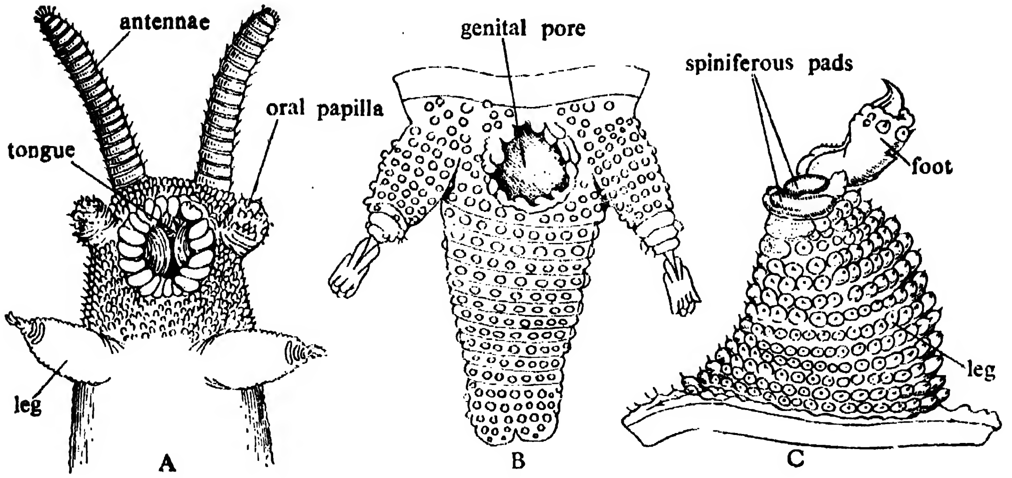


Fig. 16.116. Magnified view of different parts of *Peripatopsis*. A. Head. B. Posterior end. C. A leg (after Hegner).

16.116C). The tip bears a white flat pad and two slender claws within a pocket. Entire surface of the leg consists of numerous papillae. The *anus* which serves as the outlet of alimentary canal is present at the posterior end and behind the last pair of legs. The *reproductive opening* or *genital pore* is placed just in front of the anus (Fig. 16.116B).

Integumentary system

The epidermis is made up of a single layer of cells and situated immediately beneath the *cuticle*. The body is covered externally by a flexible chitinous cuticle which is nearly 1 mm in thickness. The *hypodermis* bears numerous short *papillae*, each containing a small fine seta. Various pigments which are responsible for its colouration are present in the hypodermis.

Muscular system

Beneath the hypodermis, following annelid-like smooth muscles are arranged from outside to inside: (*i*) *Circular*, (2) *Diagonal* and (3) *Longitudinal*. The dorso-ventrally arranged muscles divide the body cavity into two *lateral* and one *median* cavity. All the muscles are operated by the turger pressure of the body fluid. In addition to the muscles of the body wall, there are muscles which remain connected with the mouth, pharynx, jaws and alimentary canal. It may be mentioned that the jaw muscles are striated.

Locomotion

Peripatus moves by walking on all its legs excepting the first three anterior pairs. While walking, the legs raise the body above the ground. On slippery surface, the claws are extended. Each leg, while on ground, pushes backward thus its proximal attachment with the body moves forward. The leg is then raised and carried forward. The leg touches the ground only after the completion of forward movement. It has been calculated that a group of peripatus, *Peripatopsis*, measuring 5–6 cm in length, can attain a speed of 50–60 cm per minute. Peripatus can easily crawl through crevices or holes which are much smaller than the diameter of its body.

Body cavity

The major part of the body cavity is haemocoelic and is known as *mixocoel*. The mixocoel extends as four compartments—one *central*, two *laterals* and one *pericardial*. The lateral compartments extend within the legs. True coelom is restricted to the gonadal cavities and excretory organs.

Digestive system

The digestive system consists of *alimentary canal* and *digestive glands* (Fig. 16.117A).

ALIMENTARY CANAL. It begins with *mouth* which is present immediately behind the oral papillae. The mouth is enclosed by the oral or peribuccal lobes which form a *preoral cavity*. The *mandibles* or *jaws* are present within the cavity and remain posteriorly directed. Each mandible is provided with a small base and a pair of sickle-shaped, tooth-like claws. The jaws work

independent of each other and operate from anterior to posterior end. The mouth leads into a *pharynx*. The cavity of pharynx is lined by chitin and in cross-section it appears X-shaped. The wall of the pharynx is raised to increase the cavity. Such movement of pharynx produces a sucking action. The pharynx opens to the chitinous *oesophagus* having weak muscular wall. The oesophagus leads to a straight *mid gut* which is lined by endoderm. The *caeca* are absent. The mid gut enters into the hind gut which in turn communicates to the exterior by an aperture, *anus*. The hind gut is lined by chitin.

DIGESTIVE GLANDS. Most important digestive gland is a pair of *salivary glands*. Each salivary gland is slender, tubular and elongated. The salivary glands extend from third to tenth and sometimes up to thirty-first segment. The two *salivary ducts* fuse and open within the preoral lobe. In some forms, a reservoir is present. The *lining of mid gut* is also responsible for producing digestive juices.

MECHANISM OF NUTRITION. Peripatus is insectivorous and its food includes insects like grasshopper. A prey, when detected, is captured by the spurting of slime from slime gland. It is then held firmly by the lips and sucking action of the pharynx. The jaws work to slit open the prey and saliva, containing various enzymes, is poured over the victim through the slit. The saliva digests the soft part of the prey and these nutritive fluids are drawn in. The peristaltic action of the mid gut wall forces the material to pass posteriorly through its lumen. The cells of the mid gut secrete a thin membrane around the food particles. Various juices from the lining of the mid gut penetrate this membranous envelope and digests the food further. The digested materials come out of the membrane and are absorbed by the *absorptive cells* in the mid gut lining. The residual matters which remain within membrane gradually pass to the hind gut and are finally ejected through the anus.

Respiratory system

Respiratory organs are network of tracheae. The tracheal tubes are usually delicate, distally branched and possess faint transverse striations. The tracheal openings are scattered over the surface of the body and are placed in the depressions between the papillae or ridges of the skin. Each metamere contains nearly 75 spiracles. The tracheal system of Peripatus is markedly different from that of cockroach in that the spiracles in this case are devoid of any closing mechanism. The condition, however, adversely affects the animal by loss of water in great quantity.

Vascular system

Heart is a median tube placed on the dorsal side of the gut. It extends from the metamere bearing first pair of legs to the metamere immediately before last. It is enclosed by a *pericardial sinus* with which it communicates through paired *ostia*. The ostia are segmentally arranged and their number depends upon the number of segments. No other definite blood vessel is found. The pericardial sinus is separated from the general body cavity by a longitudinal partition.

Excretory system

Excretion is carried by (1) *nephridia*, (2) *mid gut lining* and (3) *pericardial cells*. The nephridia (Fig. 16.117B) are paired structures, segmentally arranged in the lateral chamber of the body cavity and correspond to the pairs of legs. A typical nephridium consists of a long *ciliated funnel*, a *coiled duct* and a contractile bladder called *vesicle*. The first three pairs of nephridia are poorly developed and each bears a vesicle and a duct. The coiled part consists of following portions—a tightly packed part that ends through a spacious opening and the elongated part that leads to the vesicle. The vesicle communicates to the exterior on the ventral surface of the legs by a narrow passage. It has been observed in *Peripatopsis* that nephridia release a drop of urine after 3–4 days. The urine contains various nitrogenous compounds but not urea. Nephridia of Peripatus are, however, analogous to the nephridia of annelids but homologous to such excretory organs of arthropods. In both, these are in the form of modified coelomoducts. For this reason, recent workers prefer to call them coelomoducts and not nephridia. Certain cells in the mid gut lining collect uric acid crystals as excretory products. Pericardial cells act as nephrocytes to remove excretory products from blood. Following glands of peculiar nature

are present in the body of Peripatus. These act as excretory organs.

Coxal or *Crural glands*. Many, paired and serially arranged glands are present on the compartments belonging to the sides of the body cavity. Their ducts open to the undersurface of the legs just outside the excretory pores. The glands are usually present only in males.

Anal glands. A pair of glands having uncertain functions open close to the anus. These are probably modified excretory organs.

Nervous system

Nervous system (Fig. 16.117B) consists of *brain* and a pair of *longitudinal nerve cords*, *peripheral nerves* and *sense organs*. Brain is present in the head region and is constituted by a pair of compactly united *supra-oesophageal ganglia*. A pair of *circumoesophageal connectives* unite the brain with the ventral nerve cord. The entire area of brain may be divided into three parts: (*a*) *Protocerebrum*. It is the portion which lies within the prostomium and it contains a central body and a pair of globuli. It sends optic nerves. (*b*) *Deutocerebrum*. It consists of a prominent antennal glommerulus and sends antennary nerves. (*c*) *Tritocerebrum*. It is the smallest part of the brain which sends nerves to the mouth and the anterior region of the gut. The two longitudinal ventral nerve cords extend up to the posterior end along the two sides

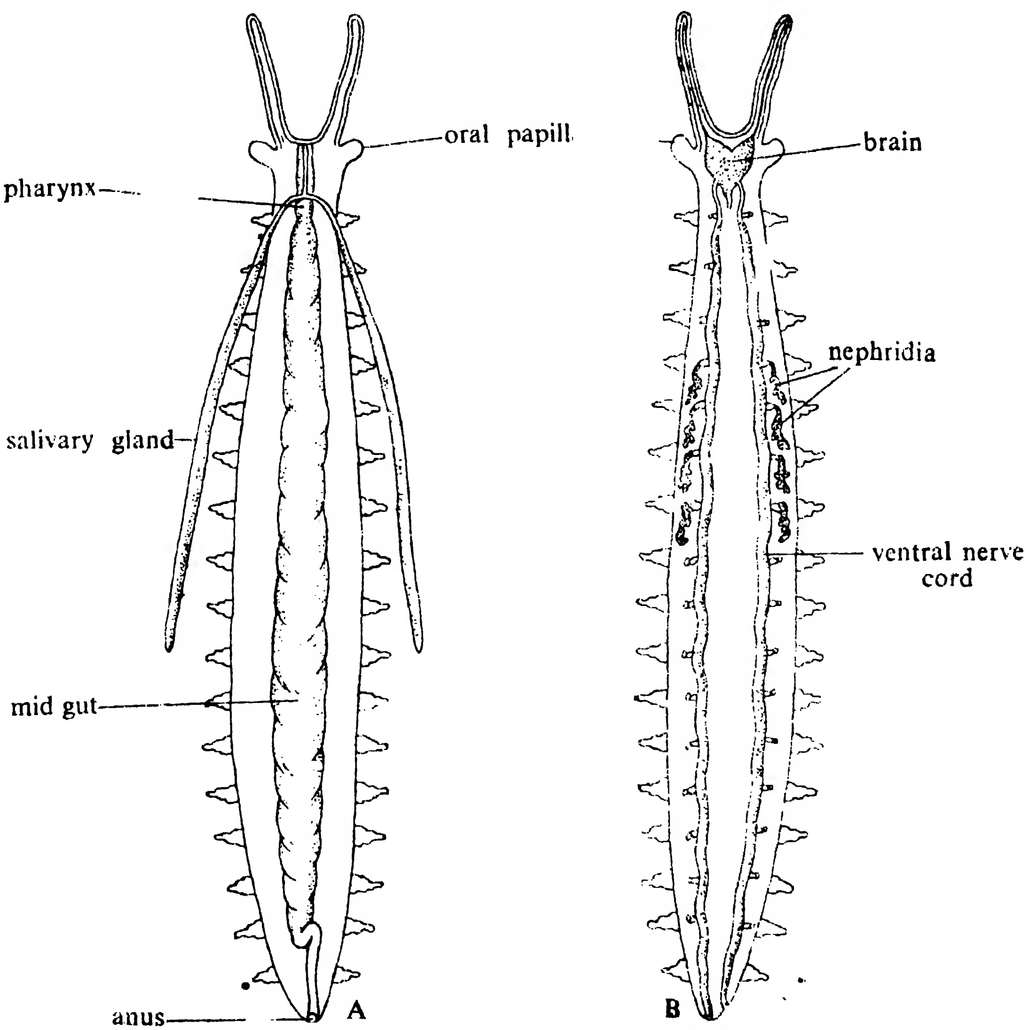


Fig. 16.117. A. Digestive system of Peripatus. B. Nervous and excretory systems of *Peripatopsis* (only a few nephridia are shown).

of the alimentary canal and unite near the anus. Along its entire length the two cords are connected by several transverse connectives and are separated from each other by dorso-ventral muscle strands. One pair of simple and small eyes are present at the base of the antenna. Each eye is 0·2–0·3 mm in diameter, cup-like in appearance and has an outer cuticular cornea and thick lens (Fig. 16.118). In the inner layer the rod

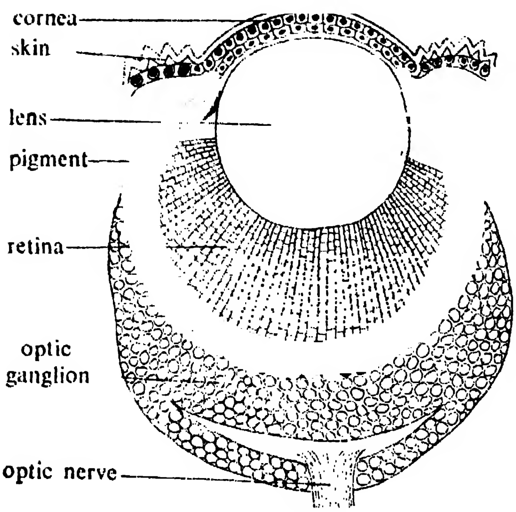


Fig. 16.118. Sectional view of the eye of Peripatus.

cells of retina are projected towards the lens at one end. The other end is connected with the branches of the optic nerve. Eyes can only feel the difference between light and shade and the animal moves away from light. The sensory cells which are present on the antenna are responsible to feel the way during locomotion.

Numerous sensory papillae are distributed all over the body. Each papilla consists of a seta and group of sensory cells. These are responsible for determining air currents and also act as tactile receptors. Specialised sensory cells are also present in the lining of buccal cavity to determine the taste of the food.

Reproductive system

Sexes are separate. Males are usually smaller than females. In males, the reproductive organs are one pair of tubular structures called, *testes*. From each testis a slender *vas deferens* opens through a funnel-like aperture into the *vesicula seminalis*. An elongated slender and coiled *vas deferens* arises from the vesicula seminalis and unites with its fellow from the other side to form a central tube called *ejaculatory duct*. The proximal part of the ejaculatory duct secretes a substance which packs the sperm cells to form *spermatophores*. The ejaculatory duct opens ventrally end between the last pairs of legs. In females the reproductive organs, called ovaries, are also a pair of tubular organs. Two ovaries are fused at the anterior and posterior ends. From each ovary arises an *oviduct* which runs anteriorly and then bends to form a curved uterus. The two uteri unite to form a median *vagina*, which opens to the exterior through an opening which occupies the same position as in males. In some forms, a process called *ovipositor* is present near the genital aperture.

Development

Most of the species are viviparous. But there may be oviparous and ovoviviparous forms. Some oviparous forms lay eggs with hard shell. The size of the egg varies from 0·05 mm to 2 mm in diameter. The fertilization is internal. At the time of reproduction, the male deposits spermatophores on any part of the body of the female. Each spermatophore measures 0·2 mm in length and a female may receive 180 spermatophores within a fortnight. In the female body numerous leucocytes appear within next 7–10 days in the area near spermatophores. These leucocytes dissolve the skin and cuticle of the female and that of spermatophores. The sperm cells enter within the female body and flow in the blood. After reaching the ovary, the sperms fertilize the eggs. Most sperms are consumed by the immature ova. The pattern of development varies in different forms. In the viviparous forms the eggs remain within oviduct for 6–13 months, where development continues. The limbs and jaws originate in the same manner, that is, as external projections. In some groups a connection between the mother and the embryo is seen. New born young of *Peripatopsis* measures 22 mm in length. The moulting occurs after every 13–18 days and the thrown out skin is eaten up. Peripatus lives for 6–7 years.

Affinities

The features of Peripatus have made it difficult to place it within any one of the ten major phyla. The detailed studies of

Peripatus have now confirmed that in addition to its own peculiar features it has characters common with three other large groups, Annelida, Arthropoda and Mollusca. An account of such relationship is given below:

A. *Relationship with Annelida.* Following features in Peripatus are akin to the annelids: (1) Segmentation in both is homonimus. (2) Presence of paired nephridia in almost every segment of the body. (3) Reproductive tracts are lined by cilia. (4) Skin is thin and flexible. (5) True head is absent. (6) Structure of the eye is same as in polychaetes. (7) Slime glands and coxal glands correspond with the similar glands of chaetopoda. (8) Appendages are hollow. (9) Musculature is smooth and muscles operate in identical way.

B. *Relationship with Arthropoda.* Following features show that Peripatus is more related to arthropoda: (1) The appendages are provided with claws. (2) Locomotion is not annelid-like but takes place with the help of legs having definite musculature. (3) Jaws are modified appendages. (4) Presence of lateral ostia as doors between the heart and pericardial sinus. (5) Presence of haemocoel or mixocoel. (6) Absence of perivisceral part of coelom. (7) Body is covered with chitinous cuticle. (8) Jaws are provided with striated muscles. (9) Brain is large and resembles the brain of typical arthropods. (10) Presence of tracheae as respiratory organs. (11) Salivary glands formed by the modification of nephridia. (12) Patterns of development is same as in other arthropods.

In spite of these similarities, Peripatus differs in many respects from the arthropods. (1) Arrangement of tracheae is not arthropod-like. Here in each segment there are numerous permanently opened spiracles. (2) Jaw is the modification of second appendage and the movements of jaws operate from anterior end and proceed towards posterior end. (3) Formation of skin is not like that of arthropods (4) Segments behind head are simple and identical. (5) Two ventral nerve cords are widely separated. (5) Structure of eye is less complicated.

C. *Relationship with Mollusca.* Slug-like appearance and ladder-like nervous system of peripatus resemble chiton and lower prosobranchiata. These led to include Peripatus among mollusca. But according to many scientists these semblances are only superficial.

The characters of Peripatus have made it most interesting from the point of view of evolution. It is an oldest terrestrial group which probably originated from some marine ancestors. It has attained a number of features for terrestrial life, i.e. internal fertilization, viviparity, semi-solid excretory product, less permeable skin, etc. But at the same time the structure of spiracles speaks about its limitation on land life and thus shows its primitiveness. The resemblances with annelids are probably the examples of convergence. The arthropodan features of Peripatus advocate a more closer relationship between the two. At the same time it shows marked differences from all the four classes of Arthropods. Instead of calling Peripatus as a living example of transitory phase from annelid to arthropod it is logical to assume that present day arthropods and the onychophores both originated separately from a common ancestor. The onychophores remained as a blind alley but survived with all its primitiveness.

CLASSIFICATION

The phylum Arthropoda includes the largest number of animals. Such animals exhibit varied ranges of diversities. In spite of this diversity, the members of this phylum have some common features. In addition, the arthropods carry some annelid features, specially resembling the chaetopods.

The presence of both unified and diversified features, have always made its classification difficult. Formerly arthropods together with annelids were included within a single group—*Annulosa.* But later studies separated them.

The classification, as followed in the text book of Parker and Haswell, shows that the phylum Arthropoda is divided into seven subphyla. The subphyla are:

Subphylum I. Onychophora
Subphylum II. Tardigrada
Subphylum III. Pentastomida
Subphylum IV. Trilobitomorpha
Subphylum V. Chelicerata
Subphylum VI. Pycnogonida
Subphylum VII. Mandibulata

In recent studies considerable rearrangement has been made in the scheme of arthropod classification.

The classification given below is based primarily on the studies of Vandel, A ('In-Traite de Zoologie, Tome VI, ed. P. Grassaé' pp. 79—158, 1949) and Snodgrass, R. E. (Arthropoda, in 'McGraw-Hill Encyclopedia of Science and Technology' Vol. I, McGraw-Hill, New York, 1960). Excepting trilobites, the other extinct arthropods are not included in the present account.

CLASSIFICATION IN OUTLINE

PHYLUM ARTHROPODA

I. SUBPHYLUM TRILOBITOMORPHA or TRILOBITA

(*i*) CLASS **Trilobita,** e.g. *Agnostus*, *Trinucleus*.

II. SUBPHYLUM ARACHNOMORPHA or CHELICERATA

(*i*) CLASS **Merostomata**

Order *Xiphosurida*, e.g. *Limulus*; *Tachypleus*.

(*ii*) CLASS **Arachnida**

Order *Scorpionida*, e.g. *Palamnaeus*, *Buthus*.
Order *Uropygi*, e.g. *Mastigoproctus*, *Trithyreus*.
Order *Amblypygi*, e.g. *Sarax*, *Myodalis*, *Tarantula*.
Order *Palpigradi*, e.g. *Eukoenenia*, *Prokoenenia*.
Order *Araneida*, e.g. *Araneus*, *Argiope*, *Lycosa*, *Latrodectus*.
Order *Ricinulei*, e.g. *Cryptocellus*, *Ricinoides*.
Order *Pseudoscorpionida*, e.g. *Garypus*, *Faella*.
Order *Solifugae*, e.g. *Galeodes*, *Eremobates*.
Order *Opiliones*, e.g. *Trogulus*, *Mitobates*.
Order *Acarida*, e.g. *Trombicula*, *Argas*, *Boophilus*, *Dermacentor*.

(*iii*) CLASS **Pycnogonida,** e.g. *Nymphon*, *Pycnogonum*.

III. SUBPHYLUM MANDIBULATA

(*i*) CLASS **Crustacea**

(1) *Subclass* Cephalocarida.
Order *Cephalocarida*,
e.g. *Hutchinsoniella*, *Lightiella*.

(2) *Subclass* Branchiopoda.
Order *Anostraca*,
e.g. *Artemia*, *Branchipus*.
Order *Notostraca*,
e.g. *Triops*, *Lepidurus*.
Order *Diplostraca*,
e.g. *Leptodora*, *Daphnia*.

(3) *Subclass* Ostracoda.
Order *Mydocopa*,
e.g. *Philomedes*, *Cypridina*.
Order *Cladocopa*, e.g. *Polycope*.
Order *Platycopa*, e.g. *Cytherella*.
Order *Podocopa*,
e.g. *Cypris*, *Darwinula*.

(4) *Subclass* Mystacocarida
e.g. *Derocheilocaris*

(5) *Subclass* Copepoda.
Order *Calanoida*,
e.g. *Calanus*, *Diaptomus*.
Order *Harpacticoida*,
e.g. *Attheyella*, *Harpacticus*.
Order *Cyclopoida*,
e.g. *Cyclops*, *Ergasilus*.
Order *Notodelphyoida*,
e.g. *Notodelphys*, *Doropygus*.
Order *Monstrilloida*, e.g. *Monstrilla*.
Order *Caligoida*,
e.g. *Caligus*, *Eudactylina*.
Order *Lernaeopodoida*,
e.g. *Brachiella*, *Lernaea*.

(6) *Subclass* Branchiura
Order *Branchiura*,
e.g. *Argulus*, *Dolops*.

(7) *Subclass* Cirripedia.
Order *Thoracica*,
e.g. *Balanus*, *Lepas*.
Order *Acrothoracica*,
e.g. *Cryptophialus*, *Trypetesa*.
Order *Apoda*, e.g. *Proteolepas*.
Order *Rhizocephala*,
e.g. *Sacculina*, *Peltogaster*.
Order *Ascothoracica*,
e.g. *Synagoga*, *Dendrogaster*.

(8) *Subclass* Malacostraca.
1. Super order Phyllocarida
Order *Nebaliacea*,
e.g. *Nebaliopsis*, *Nebalia*.

2. Super order Hoplocarida
Order *Stomatopoda*,
e.g. *Squilla*, *Coronida*.

3. Super order Syncarida
Order *Anaspidacea*,
e.g. *Anaspides*, *Paranaspides*.

4. Super order Peracarida
Order *Mysidacea*,
e.g. *Mysis*, *Neomysis*.
Order *Cumacea*,
e.g. *Cumopsis*, *Diastylis*.
Order *Tanaidacea*,
e.g. *Tanais*, *Neotanais*.
Order *Isopoda*,
e.g. *Oniscus*, *Ligia*.
Order *Amphipoda*,
e.g. *Gammarus*, *Caprella*.

5. Super order Eucarida
Order *Euphausiacea*,
e.g. *Euphausia*, *Nematoscelis*.
Order *Decapoda*,
e.g. *Palaemon*, *Homarus*, *Palinurus*, *Scyllarus*, *Hippa*, *Eupagurus*, *Cancer*.

(*ii*) Class **Chilopoda**
Order *Scutigeromorpha*,
e.g., *Scutigera*.
Order *Lithobiomorpha*, e.g. *Lithobius*.
Order *Scolopendromorpha*,
e.g. *Scolopendra*.
Order *Geophilomorpha*, e.g. *Geophilus*.

(*iii*) Class **Symphyla,**
e.g. *Scutigerella*, *Scolopendrella*.

(*iv*) Class **Pauropoda,** e.g. *Pauropus*.

(*v*) Class **Diplopoda**

(*a*) *Subclass* Pselaphognatha
Order *Pselaphognathae*,
e.g. *Polyxenus*.

(*b*) *Subclass* Chilognatha.
Order *Platydesmida*, e.g. *Platydesmus*.
Order *Polyzoniida*, e.g. *Polyzonium*.
Order *Polydesmida*, e.g. *Polydesmus*.
Order *Chordeumida*, e.g. *Chordeuma*.
Order *Julida*, e.g. *Julus*.
Order *Spirobolida*, e.g. *Spirobolus*.
Order *Spirostreptida*, e.g. *Thyropygus*.

(*vi*) Class **Insecta or Hexapoda**

(*a*) *Subclass* Apterygota

1. Super order Entognatha
Order *Protura*,
e.g. *Eosentomon*, *Acerentomen*.
Order *Collembola*,
e.g. *Isotoma*, *Neanura*.
Order *Diplura*,
e.g. *Campodea*, *Heterojapyx*.

2. Super order Ectognatha
Order *Thysanura*,
e.g. *Lepisma*, *Machilis*.

(*b*) *Subclass* Pterygota

1. Section PALEOPTERA
Order *Ephemeroptera*,
e.g. *Ephemera*. *Hexagenia*.
Order *Odonata*,
e.g. *Aeschna*, *Libellula*, *Ischnura*.

2. Section POLYNEOPTERA
Order *Dictyoptera*,
e.g. *Periplaneta*, *Mantis*.
Order *Isoptera*, e.g. *Termes*, *Odontotermes*.
Order *Zoraptera*, e.g. *Zorotypus*.
Order *Plecoptera*,
e.g. *Perla*, *Isoperla*.
Order *Notoptera*, e.g *Grylloblatta*
Order *Cheleutoptera*,
e.g. *Carausius*, *Phyllium*
Order *Orthoptera*,
e.g. *Hieroglyphus*, *Tryxalis*, *Locusta*, *Schistocerca*, *Gryllotalpa*.
Order *Embioptera*, e.g. *Embia*.
Order *Dermaptera*, e.g. *Forficula*.

3. Section OLIGONEOPTERA
Order *Coleoptera*,
e g. *Photinus*, *Calandra*, *Adalia*, *Dineutus*.
Order *Megaloptera*,
e.g. *Sialis*, *Corydalis*.
Order *Raphidioptera*, e.g. *Raphidia*.
Order *Planipennia*,
e.g. *Mantispa*, *Myrmeleon*.
Order *Mecoptera*, e.g. *Panorpa*.
Order *Trichoptera*, e.g. *Rhyacophilia*.
Order *Lepidoptera*, e.g. *Parides*, *Papilio*, *Bombyx*.
Order *Diptera*, e.g. *Anopheles*, *Musca*.
Order *Siphonaptera*, e.g. *Pulex*, *Ctenocephalus*.
Order *Hymenoptera*, e.g. *Apis*, *Vespa*, *Formica*.
Order *Strepsiptera*, e.g. *Stylops*.

4. Section PARANEOPTERA
Order *Psocoptera*, e.g. *Psocus*.
Order *Mallophaga*, e.g. *Menopon*.
Order *Anoplura*, e.g. *Pediculus*.
Order *Thysanoptera*, e.g. *Heliothrips*.
Order *Homoptera*, e.g. *Cicada*, *Aphis*, *Tachardia*.
Order *Heteroptera*, e.g. *Cimex*, *Anasa*, *Triatoma*.

The **ONYCHOPHORES, TARDIGRADES** and **PENTASTOMIDS** are now regarded by some textbook writers as classes having uncertain systematic position (Fox & Fox, 1949). Hegner and Engemann (1968) preferred to incorporate Onychophora as a separate subphylum and Tardigrada and Pentastomids as separate classes under the subphylum Chelicerata. Wilmoth (1967) has treated these three groups as *Pararthropods*. Similar view is also followed by Kaestner (1968), who has included each group within a separate phylum. Parker and Haswell (1972) have placed all the species under twelve genera of Peripatus under a separate subphylum Onychophora. They represent a group which diverged from the basic arthropodan stock.

CLASSIFICATION WITH CHARACTERS

SUBPHYLUM TRILOBITOMORPHA OR TRILOBITA

Extinct marine arthropods, having two distinct regions or tagmata, *prosoma* and *opisthosoma*. Body is more or less oval and divided into three lobes by two longitudinal furrows. Size varies from 10 mm to 60 cm. A pair of many-jointed antennae represent the preoral appendages. Appendages are uniform and unspecialised. Each leg has eight articles or segments. The subphylum includes 4000 species, which are grouped under five classes. The class which includes the largest number of species is known as the *Trilobita*. The well-known examples are *Agnostus*, *Trinucleus*.

SUBPHYLUM ARACHNOMORPHA OR CHELICERATA

Heterogenous group of arthropods, in all of which preoral antennules or first antennae are absent. Body is divided into two parts—*cephalothorax* and *abdomen*. Cephalothorax possesses five postoral segments, each with a pair of appendages. First pair of appendages on the first postoral segment is called *chelicerae*. It is jointed and bears a terminal chela. The chelicerae become preoral in position. Abdomen consists of 12–13 segments and a telson (telson and many abdominal segments are absent in certain forms). Second abdominal segment bears genital aperture which remains covered by a modified abdominal appendage called *operculum*. Compound eyes in most cases are degenerated. Median ocelli are present. Development is usually direct. It includes two classes—Merostomata and Arachnida.

CLASS **Merostomata**

Aquatic forms with fairly developed compound eyes. Abdomen is subdivided into a 7-segmented mesosoma and 5-segmented metasoma. Prominent caudal spine is present. Mesosoma bears 4–5 pairs of appendages. Respiratory organs are gills. Adults crawl on earth with the face downwards, but young can swim actively. It includes one living order *Xiphosurida*

Order *Xiphosurida*

These bottom dwellers are commonly known as horse-shoe crabs. Cephalothorax is covered by a broad carapace. Caudal spine is elongated, slender and pointed. Dorsal ridge is visible in the abdomen. Excretion is carried by a four-lobed coxal gland. Development includes a larval stage, called trilobite larva, e.g. *Limulus*, *Tachypleus*.

CLASS **Arachnida**

Body is divided into two regions—cephalothorax and abdomen. Eyes are usually simple. Compound-eyes when present are degenerated. Two pairs of jointed appendages—*chelicerae* and *pedipalpi*, are present. Four pairs of thoracic legs are present. Abdominal segments are often reduced and abdominal appendages do not take part in locomotion. Antennae are absent. Ingests only liquid food. In the forms with aerial respiration, the respiratory organs are either *book lungs* or *tracheae*, and in certain forms the respiration may be cutaneous. Sexes are separate. Development is not accompanied by metamorphosis. Ten orders—Scorpionida, Uropygi, Amblypygi, Palpigradi, Araneida, Ricinulei, Pseudoscorpionida, Solifugae, Opiliones and Acarida are placed under this class.

Order *Scorpionida*. This order includes scorpions. Abdomen is divisible into two parts—broad pre-abdomen (seven segments) and narrow post-abdomen (five segments). Pre-abdomen is as wide as the cephalothorax. Post-abdomen bears a caudal spine formed by the modification of telson. It contains poison gland. Chelicerae are small 3-segmented but pedipalpi are

large and 6-segmented. Second segment of the pre-abdomen bears two comb-shaped pectines. Four pairs of respiratory organs, called *book lungs*, are associated with the third, fourth, fifth and sixth segments of the pre-abdomen. Viviparous, e.g. *Palamnaeus*, *Buthus*, *Scorpio*.

Order *Uropygi*. These are commonly called whip scorpions. Size ranges from 2–65 mm in length. Telson is present as a long whip-like flagellum at the posterior end. Nocturnal and carnivorous. Poison glands are absent but an acidic substance from the anus is sprayed. Female is provided with a brood sac to carry eggs. Upper lip of the rostrum and the bases of the pedipalps form a peculiar ball and socket-joint around the mouth to act as a filtering apparatus. Pedipalp is short and stout. Second leg is antenna-like and elongated. Abdomen bears 12-segments. Book lungs are placed on the second and third abdominal segments, e.g. *Mastigoproctus*, *Trithyreus*.

Order *Amblypygi*. Commonly known as tailless whip scorpions. Size varies from 4–45 mm in length. Body is flattened dorso-ventrally. Telson is almost absent. Abdomen consists of 11 segments. Chelicerae are 2-jointed and hook-like. Pedipalps consist of seven segments and are stout and raptorial. A prominent movable claw is present at the distal end of each pedipalp. Book lungs open on the ventral side of second and third abdominal segments. Females carry brood-sacs during breeding season. The common example is *Tarantula*.

Order *Palpigradi*. Commonly called microwhipscorpions. Size ranges from 0·5–3 mm in length. In the cephalothorax last two segments are not united. Abdomen has eleven segments. Telson looks like many-jointed flagellum. Chelicerae are 3-segmented and chelated. Pedipalpi are leg-like. Both simple and compound eyes are absent. Second pair of legs act as antennae. Respiration is cutaneous. In addition, paired eversible sacs in the abdominal segments also act as respiratory organs, e.g. *Eukoenenia*.

Order *Araneida*. Contains large number of diverse forms which are called spiders. Cephalothorax is unsegmented. Abdomen in general is also unsegmented, soft and round. Four pairs of eyes are present. Chelicerae are complex and poison glands open through them. Pedipalpi are simple and six-jointed. Possesses sucking stomach and diverticula. Book lungs are associated with trachea for respiration. Spinning glands usually present and appendages of fourth and fifth abdominal segments form spinnerets. The well-known examples are *Argiope*, *Latrodectus*.

Order *Ricinulei*. Commonly called Ricinuleids. Sizes usually less than 10 mm in length. Body is short and compact. Cephalothorax is drawn anteriorly into a movable projection, called *cucullus*. Eyes are absent. Abdomen superficially looks like four segmented but truly it consists of nine segments. Both the chelicerae and pedipalpi are chelated. Tracheae are the respiratory organs. The well-known examples are *Cryptocellus*, *Ricinoides*.

Order *Pseudoscorpionida*. These are commonly called pseudoscorpions. Size is never more than 8 mm in length. Body is oval and flattened dorso-ventrally. Abdomen is broad and consists of eleven segments. Abdomen is not separated into pre- and post-abdomen and does not bear the caudal sting. Simple eyes are absent. Chelicerae are small and contain silk glands. Pedipalpi are scorpion-like and contain poison glands. Respiratory organs are tracheae. Malpighian tubules are absent. Oviparous. The well-known examples are *Chelifer*, *Neobisium*.

Order *Solifugae*. Commonly known as wind scorpions. Size varies from 1–7 cm in length. These are swift runners. Body is divided into three regions—head, thorax and abdomen. Abdomen is oval and contains ten segments. Chelicerae are large and prominent. Pedipalpi are elongated and resemble the legs. Poison glands are absent. Respiratory organs are well-developed tracheae. All are nocturnal, ferocious and predators. The well-known examples are *Galeodes*, *Eremobates*.

Order *Opiliones*. Commonly called harvestmen. Size varies from 1–22 mm in length. Cephalothorax is unsegmented. Abdomen consists of ten segments and is not distinctly separated from the cephalothorax. Telson is absent. Compound eyes are lacking. Pedipalpi are leg-like. Walking legs are usually very long and slender. Respiration takes place through tracheae. No poison or spinning glands are present. Males possess copulatory organ and females are provided with ovipositor. The well-known examples are *Caddo*, *Phalangium*, *Trogulus*, *Mitobates*.

Order *Acarida.* Commonly known as ticks and mites. Number of forms are microscopic in sizes. Body is without any external division. Mouth parts are variously modified in different forms—biting, piercing or sucking. Chelicerae are usually composed of 2 to 3 segments but may have up to 6 segments. The chelicerae may be pincer-like, fang-like or lance-like. Pedipalpi also may be variously modified. Legs are provided with claws. Respiratory organs are tracheae and in many respiration is cutaneous. Most of them are parasites on man and other animals. Some are notorious pests of agricultural products. The well-known examples are *Tetranychus*, *Argas*, *Demodex* and *Sarcoptes*.

Class **Pycnogonida**

These partially sedentaric marine animals are commonly called sea spiders. Youngs are parasitic on different soft-bodied invertebrates. Reproductive openings are present on the leg segments and not abdominal. Chelicerae are short and pedipalpi are segmented. Third pair of appendages in the male carries the eggs and is called the *ovigers.* A distinct proboscis is present at the anterior end. Abdomen is much reduced and contains 2–3 segments. The well-known living representative is *Nymphon.*

SUBPHYLUM MANDIBULATA

Body is distinctly divisible into two parts —*head* and *trunk.* The trunk in many, may be subdivided into *thorax* and *abdomen.* Three preoral segments are fused and bear various structures like antennae, compound eyes and simple eyes, Respiration is carried by gills, tracheae or skin. It includes six classes—Crustacea, Chilopoda, Symphyla, Pauropoda, Diplopoda and Insecta.

Class **Crustacea**

Body is divisible into three distinct regions—*head*, *thorax* and *abdomen.* Six head segments are fused and in many instances the thoracic segments are united with the head to form *cephalothorax.* Head bears a pair of *compound eyes* on movable jointed stalk. A median eye, which is the characteristic of the larval form, may persist in the adults of some crustaceans. Cephalic appendages are five pairs and the first two pairs are *antennae;* thoracic and abdominal appendages are usually 8 pairs and 6 pairs respectively and may undergo various modifications. Each segment is covered by an immovable exoskeleton—*sclerite,* which is separated from the other by flexible chitin. Fusion of sclerites often occur. Respiration is generally performed by gills. In addition, several accessory respiratory structures may be present. Vascular system consists of distinct heart, arteries and haemocoelomic spaces. The excretory organs are the modifications of coelomoducts. Brain is formed by the fusion of first four embryonic ganglia and is connected with ventral nerve cord by oesophageal connectives. Sexes are separate. Distinct sexual dimorphism is present. Sperms are generally amoeboid. Eggs are usually *centrolecithal*, i.e. yolk present in the central part of the egg, or they may be *telolecithal* (yolk occupies one-half of the egg) or *alecithal* (without yolk). Embryo mostly passes through a *nauplius stage* which is invariably free-swimming. The class Crustacea has following subclasses: Cephalocarida, Branchiopoda, Ostracoda, Mystacocarida, Copepoda, Branchiura, Cirripedia and Malacostraca.

Subclass Cephalocarida

This new subclass was established after the discovery of the genus *Hutchinsoniella* in the year 1955. The subclass includes an order of the same name and contains two genera and three species. All the appendages after second maxillae are of identical appearance. These limbs are tripartite. Exopodites of these appendages are four-jointed and leaf-like and bear lateral pseudoepipodite. Endopodites are segmented, cylindrical and ambulatory in function. The movements of the limbs produce water current for locomotion and also for collecting food. Eyes are absent. In addition to *Hutchinsoniella,* another genus *Lightiella* is also included within it.

Subclass Branchiopoda

Appendages are uniform and leaf-like. Presence of one pair unjointed or jointed caudal styles. Carapace is either absent or shield-like or bivalve. First antennae and maxillae are small and in some cases absent. The mandibular palp is either rudimentary or absent. It has three living orders—Anostraca, Notostraca and Diplostraca.

Order *Anostraca*. It includes forms like fairy shrimps and brine shrimps. Carapace is absent. Possesses stalked eyes. Antennae are very small and triangular in females and in males they are stout copulatory structures. Trunk is elongated and first 11 segments bear alike legs. Caudal styles are unjointed. The examples are *Branchipus*, *Artemia*.

Order *Notostraca*. Commonly called Tadpole shrimp. Carapace is large and shield-shaped. Possesses 35–71 pairs of legs. Eyes are sessile and placed close together. Caudal styles are filamentous and many-jointed. Males are rare and parthenogenesis is frequent. The well-known examples are *Triops*, *Lepidurus*.

Order *Diplostraca*. It includes forms like clam-shrimps (*Estheria*) and water fleas (*Daphnia*, *Leptodora*). Laterally compressed bivalved carapace usually does not cover the head and generally fused. Biramous and large antennae are used during swimming. Caudal styles are not jointed and terminated in claw.

Subclass Ostracoda

The members belonging to this group are commonly called seed-shrimps. Body is either without any segment or poorly segmented. Trunk appendages are never more than four pairs. The mandible possesses a palp. Both the pairs of antennae are modified for swimming. Respiration is usually cutaneous. Eyes may or may not be present. Males are rare and in them the second antennae serve as clasping organs. Following orders—Mydocopa, Cladocopa, Platycopa and Podocopa are included in this subclass.

Order *Mydocopa*. The carapace bears an aperture through which the antennae protrude. Antenna is operated by powerful muscles. Limbs are four pairs. Heart possesses paired ostia. Compound eyes are sessile. The well-known examples are *Philomedes*, *Cypridina*.

Order *Cladocopa*. The aperture for the protrusion of antennae is absent. Limbs are two pairs. Each second antenna bears two branches or rami. The example is *Polycope*.

Order *Platycopa*. Antennal aperture is absent. The rami of second antennae are broad. Limbs are three pairs. The example is *Cytherella*.

Order *Podocopa*. Antennal aperture on the carapace is absent. Endopodite of the second antenna is well developed than exopodite and carries a claw. Mandibular palp is composed of four articles. Four pairs of limbs are posteriorly placed. The examples are *Cypris*, *Darwinula*.

Subclass Mystacocarida

This subclass was created after the discovery of several crustaceans in the year 1943. All of them are included under the genus *Derocheilocaris*. The length is always within 1 mm. Body is elongated with distinct cephalic appendages. Trunk consists of 15 segments. The nauplius eye persists and the compound eyes are absent. Two caudal styles work as pincers.

Subclass Copepoda

The body has well-marked segments. Among the five pairs of limbs, the last four pairs are biramous and modified for swimming. Abdominal appendages are absent. Presence of a pair of caudal styles. Paired compound eyes are usually not present but single median nauplius eye is distinct. Well-developed antennae may or may not be used for swimming. Seventh segment of the body carries the reproductive apertures. Seven orders—Calanoida, Herpacticoida, Cyclopoida, Notodelphyoida, Monstrilloida, Caligoida and Lernaeopodoida, belong to this group.

Order *Calanoida*. Free-living and size is fairly large. Posterior part of the trunk is distinctly separated from the anterior part and between genital and pregenital segments. First antennae of female have 23–25 segments. The second antenna is biramous. The female possesses a single median egg-sac. The well-known examples are *Calanus*, *Diaptomus*.

Order *Harpacticoida*. Free-living. Trunk is not constricted in the middle. First antenna in the female is short and consists of 5–9 segments. The second antenna is biramous. The common example is *Attheyella*.

Order *Cyclopoida*. Free-living. Posterior part of the trunk is separated from the anterior part and it includes pregenital segments. First antenna of female has more than 17 articles. The second antenna is uniramous. The female carries a pair of egg-sacs. Some members are parasitic. The well-known examples are *Cyclops*, *Ergasilus*, *Eucyclops*.

Order *Notodelphyoida*. Only in males the posterior half of the trunk bears pregenital segments. Both sexes live as commensal within a tunicate, *Ascidia*. The well-known example is *Notodelphys*.

Order *Monstrilloida*. Free-swimming and completely marine. Adults are without mouth parts, antennae and alimentary canal. Larva starts as a free-swimming nauplius and parasitises a mollusc or annelid. It draws nourishment by its antennae from the host. Adult, when full-grown, becomes again free-swimming and perform only reproduction. The example is *Monstrilla*.

Order *Caligoida*. Lives as ectoparasite on fishes. Posterior part of trunk carries two pregenital segments. The antennae are modified to act as adhesive organs. The examples are *Caligus*, *Eudactylina*.

Order *Lernaeopodoida*. Adults remain as ectoparasites up to the attainment of sexual maturity. The sexually matured forms become free-swimming. After copulation, female again becomes parasitic on fishes. It changes into a worm-like form and carries the eggs in a brood chamber. Larvae start as free-swimming nauplius but soon infect a new host. The well-known examples are *Lernaea*, *Lernaeocera*.

Subclass Branchiura

It includes dorso-ventrally flattened parasitic forms with suctorial mouth. Broad carapace covers the cephalothorax. Abdomen is small, unsegmented and bilobed. Sessile compound eyes are present. Flagella are present in the appendages of some body segments. The fifth body segment bears the genital apertures. Females possess single ovary but the males have two testes. It includes a single order, having the same name and the well-known example is *Argulus*.

Subclass Cirripedia

All are marine. Adults are sedentaric. Body is poorly segmented. Six pairs of biramous filamentous appendages are present. Abdomen is almost absent and instead of any appendage, carries only a pair of caudal styles. Carapace folds to form a pair of mantle which covers the entire body and bears calcareous plates on it. Adults are without eyes and antennae. Usually hermaphrodite. Young passes through nauplius and cypris stage. This subclass has five orders—Thoracica, Acrothoracica, Apoda, Rhizocephala and Ascothoracica.

Order *Thoracica*. Adults are permanently fixed by its preoral region on substrates at intertidal level. Presence of six pairs of appendages in the trunk called *cirri*. Abdomen is devoid of segments. Some forms have a stalk, others are sessile. The best examples are *Lepas* (Goose barnacles), *Balanus* (Acorn barnacles).

Order *Acrothoracica*. Sessile forms and are fixed on the shell of molluscs. Mantle devoid of calcareous plates. Presence of only four pairs of appendages in the trunk. Male lives as parasite within female. The example is *Alcippe*.

Order *Apoda*. Completely parasitic forms having small distinctly segmented body. Trunk appendages are absent. The only example is *Proteolepas*.

Order *Rhizocephala*. Completely parasitic. Mantle remains, but the calcareous shells are absent. Body is absolutely degenerated in adults due to the loss of alimentary canal and appendages. The well-known examples are *Sacculina*, *Peltogaster*.

Order *Ascothoracica*. These are endoparasites on Anthozoa and Echinodermata. Mantle is bilobed or sac-like but plates are absent. Oral appendages are modified for piercing and sucking. Presence of six pairs of appendages in the trunk. The common examples are *Synagoga*, *Laura*, *Dendrogaster*.

Subclass Malacostraca

Body consists of twenty to twenty-one segments. Thoracic and abdominal appendages are distinct from one another. Carapace covers head and at least some thoracic segments. Mandible is with a palp. Presence of compound eyes on stalk. Antennule is with two many-jointed flagella. The subclass includes five super orders—Phyllocarida, Hoplocarida, Syncarida, Peracarida and Eucarida.

Super Order Phyllocarida

Possesses a movable rostrum at the anterior end of cephalothorax. Carapace is large, bivalved and encloses both the cephalothoracic and abdominal segments. Thoracic legs are all alike and foliaceous. Abdomen has seven segments. First four abdominal segments with well-developed appendages. Telson has a movable caudal furca. It has only one order Nebaliacea.

Order *Nebaliacea.* Presence of seven abdominal segments. Telson with a pair of caudal styles. A prominent carapace covers almost the entire length of the body. Thoracic appendages are leaf-like and serve as respiratory surface. Abdominal appendages are biramous. The common example is *Nebalia.*

Super Order Hoplocarida

All are marine. Carapace is flat, shield-shaped and covers up to second thoracic segment. Two movable segments lie anterior to the carapace. The anterior one bears the stalked eyes and the posterior one carries the antennules. Each antennule has three rami. Antenna is smaller than antennule. Second pair of thoracic appendage are raptorial and bear a blade-like edge at its distal end. Abdominal appendages are biramous. Only one order Stomatopoda is included under this Super order.

Order *Stomatopoda.* Last four thoracic segments are free from the carapace. Two movable segments are present in front of the head. Gills are carried by the abdominal appendages. Gastric glands extend up to the telson. Heart extends up to abdomen and has thirteen pairs of ostia. The well-known examples are *Squilla*, *Pseudosquilla* and *Coronida.*

Super Order Syncarida

Carapace is absent. First thoracic segment is fused with head. Elongated and tube-like heart. Only the first pair of thoracic appendages are modified as maxillipeds, rest are alike. Gills are present on the thoracic appendages excepting the last one. Last pair of abdominal appendages, called uropods, are fan-shaped. It includes a single order Anaspidacea having genera like *Anaspides*, *Paranaspides* and *Bathynella.*

Super Order Peracarida

Carapace may or may not be present. When present, carapace never covers last four thoracic segments. Coxopodites of thoracic appendages bear a brood pouch in females. Presence of a tube-like, elongated heart. Five orders like Mysidacea, Cumacea, Tanaidacea, Isopoda and Amphipoda are included within the Super order.

Order *Mysidacea.* First antennae are biramous. Second antenna is with scale-like squama. Possesses filter feeding mechanism. First pair of thoracic appendages are modified as maxillipeds. Carapace is the chief respiratory surface. Broad tail fin is formed by flat uropods and telson. Heart is elongated but extends up to thorax and has two pairs of ostia. The common examples are *Mysis*, *Hemimysis.*

Order *Cumacea.* Cephalothorax is posteriorly narrow. Carapace is drawn out anteriorly to form rostrum and ventrally to form gill chamber. Sessile eyes are usually fused to form a single eye. Antennae are usually unisegmented. Second antennae are without exopodites and well developed in males than in females. Abdomen is slender and segmented. Abdominal appendages are absent in the female. Uropods are rod-shaped and thus fan-shaped tail fin is absent. The well-known examples are *Cumopsis*, *Diastylis* and *Pseudocuma.*

Order *Tanaidacea.* Carapace covers first two thoracic segments. Eyes, when present, are mounted on immovable stalks. Second thoracic appendages are large and chelated. A small squama may be present with the second antenna. Uropods are slender. The examples are *Tanais*, *Apseudes* and *Neotanais.*

Order *Isopoda.* It includes aquatic, terrestrial and parasitic forms. Carapace is absent, only first thoracic segment is fused into head. Eyes are either without stalk or they are carried on small immovable processes. Body is dorso-ventrally flattened. Antennule is small and rudimentary. First pair of thoracic appendages are modified as maxillipeds, while the others are alike. The well-known examples are *Liriopsis*, *Oniscus* (an example of crustacea which is terrestrial).

Order *Amphipoda.* Body is flattened laterally. Carapace is absent. Antennules are well developed and biramous. Second and third pairs of thoracic appendages are prehensile structures called *gnathopods.* Some thoracic appendages bear gills at their bases. Abdominal appendages are of two distinct morphological forms. The examples are *Gammarus*, *Caprella.*

Super Order Eucarida

Carapace covers head and all the thoracic segments. Mandible is without sharp blade. Eyes are carried on movable, jointed stalks. Small bag-like heart is placed on

the dorsal side of the thorax. Eucarida has two orders—Euphausiacea and Decapoda.

Order *Euphausiacea*. Thoracic appendages do not form maxillipeds and are all alike. Single gill is present at the base of each thoracic appendage. Pleopods are flattened. In the males first two pairs are modified for copulation. Elongated telson bears a movable large spine. Uropods are elongated. The examples are *Euphausia*, *Thysanopoda* and *Nematoscelis*.

Order *Decapoda*. Three maxillipeds are formed by the modification of first three thoracic appendages. Three sets of gills are present which differ in their arrangements. The well-known examples are *Palaemon*, *Homarus*, *Palinurus*, *Scyllarus*, *Cancer*, *Birgus*, *Hippa* and *Eupagurus*.

Class **Chilopoda**

Number of legs vary from fifteen to more than hundred pairs, but no form possesses even number of pairs. Nocturnal and stay in humid areas. Primarily carnivorous. Body is usually dorso-ventrally flattened. First pair of trunk appendages are modified as maxillipeds and work as poison claws. Each leg has seven articles. Segment in front of telson is called genital segment. Usually a pair of gonopods are present. Respiration is carried by means of trachea. Four well-known orders—Scutigeromorpha, Lithobiomorpha, Scolopendromorpha and Geophilomorpha are placed within this class.

Order *Scutigeromorpha*. Legs are 15 pairs and very long. Compound eyes are present. Antennae are very long and originate from the posterior region of the anterior border of head. Dorsal side of the head is arch-shaped. Almost all the trunk segments bear a median spiracle, on their dorsal side. The common example is *Scutigera*.

Order *Lithobiomorpha*. Legs are 15 pairs but very short. Antennae arise from the anterior border of the head. Head and trunk both are flattened on the dorsal side. Spiracles are laterally placed. The example is *Lithobius*.

Order *Scolopendromorpha*. Strongly built body carries 21–23 pairs of legs, only anterior part of the trunk bears lateral spiracles. On the dorsal side of the trunk long plates alternate with shorter ones. The example is *Scolopendra*.

Order *Geophilomorpha*. Number of legs varies from 35–181. Body is narrow, worm-like and the legs are small. Eyes are absent. Spiracles are placed laterally. The example is *Geophilus*.

Class **Symphyla**

It includes herbivorous or omnivorous forms. Mouth parts are directed forward. Number of segments are usually 14. The adult possess 12 pairs of legs and a pair of dorsal cerci on the thirteenth segment. Telson is absent. Second maxillae are united to constitute the labium. Spiracles are present only in the head and trachea extends posteriorly only up to first three anterior trunk segments. The organisms moult throughout life. It includes only one order Symphyla having genera like *Scolopendrella*, *Scutigerella*.

Class **Pauropoda**

Length rarely exceeds 1 mm. Saprophytic in habit. Head has five segments. First maxilla unites to form gnathochilarium. Antennae are branched. Trunk contains twelve segments. Legs are present in segments second to tenth. The class includes one order pauropoda and its example is *Pauropus*.

Class **Diplopoda**

Elongated and segmented forms, having two pairs of legs, two pairs of spiracles, two pairs of ganglia and two pairs of ostia in each segment. Usually vegetarian. Antennae are 7-segmented. Maxillae are united to form gnathochilarium. Tracheae are mostly unbranched tubes. Gonads are unpaired but reproductive ducts are paired. The class is divisible into two subclasses—Pselaphognatha and Chilognatha.

Subclass Pselaphognatha

The size of the body is very small. Body is soft due to the absence of hard exoskeleton. Gonopods are absent in males. Head contains trichobothria. Integument is often armed with lateral setae, hairs or bristles. It includes a single order Pselaphognathae and the example is *Polyxenus*.

Subclass Chilognatha

The integument is provided with hard exoskeleton. Head has no trichobothria. Setae are not clustered. Gonopods are present. Presence of gnathochilarium. The subclass includes seven orders—Platydesmida,

Polyzoniida, Polydesmida, Chordeumida. Julida, Spirobolida and Spirostreptida.

Order *Platydesmida*. All parts of the gnathochilarium are present. A prominent groove is present in the middle line of the dorsal surface. The example is *Platydesmus*.

Order *Polyzoniida*. Only a triangular plate is present in the gnathochilarium, other parts are obscure. No median groove is present on the dorsal side. The example is *Polyzonium*.

Other *Polydesmida*. The segments vary from 18–22. Lines of fusion between the exoskeletal plates are indistinct. The dorsal plate, tergum, projects laterally as parnota. Eyes are absent. Only the first pair of legs in the seventh segment are modified as gonopods. The example is *Polydesmus*.

Order *Chordeumida*. Number of segments are always more than thirty. Ventral plates are separated by sutures. Eyes are distinct. Both the pairs of legs in the seventh segment act as gonopods. Last segment bears 1–3 pairs of spinnerets. The example is *Chordeuma*.

Order *Julida*. Spinnerets are not present on the last abdominal segment. Both pairs of legs of the seventh segment are modified as gonopods; in some cases one pair may be absent. The example is *Julus*.

Order *Spirobolida*. Gnathochilarium is free from mentum. Only one pair of legs are present in the fifth segment. The example is *Spirobolus*.

Order *Spirostreptida*. Possesses two pairs of legs in the fifth segment. Second or posterior gonopods are almost absent. A small tail is usually present. The example is *Thyropygus*.

These arthropods belonging to Chilopoda, Symphyla, Pauropoda and Diplopoda were formerly included under the class Myriapoda. The word 'Myriapoda' is still used to refer these animals, but is now out of taxonomic usage.

Class **Insecta or Hexapoda**

Size varies from 250 micra to 25 cm in length. Body consists of three distinct tagmata—head, thorax and abdomen. The head is formed by the fusion of six segments and its appendages are—a single pair of *antennae*, a pair of *mandibles* and two pairs of *maxillae*. Mouth parts vary according to food habit. In adults, the thorax includes three segments—*Prothorax*, *Mesothorax* and *Metathorax*. Each of these segments bears one pair of legs on the ventral side. Each leg usually consists of six segments. One or two pairs of wings are present on the dorsal side of the thorax. Paired appendages are absent in the adult abdomen. Respiratory organs are in the form of tracheae which are extensively developed. Salivary glands are the important digestive glands. The chief excretory organs are Malpighian tubules which remain closely associated with alimentary canal. Development usually passes through complicated metamorphosis but in some cases it may be direct. It has two subclasses—Apterygota and Pterygota.

Subclass Apterygota

The wings are absent. Presence of terminal cerci. Development is direct. Two super orders—Entognatha and Ectognatha belong to this subclass.

Super Order Entognatha

Labium being united with the cranium on the lateral side, completely covers the mandibles and maxillae. Three orders—Protura, Collembola and Diplura are present within this super order.

Order *Protura*. Abdomen has twelve segments in the adult. Rudimentary appendages are present on the first three abdominal segments. Compound eyes and antennae are not present. The examples are *Acerentomon* and *Eosentomon*.

Order *Collembola*. The members are commonly called the springtails. Abdomen never possesses more than six segments. Eyes, Malpighian tubules and usually the tracheae are absent. Last segment carries appendages for jumping. The examples are *Podura*, *Orchesella*, *Bourletiella*, *Isotoma* and *Neanura*.

Order *Diplura*. Abdomen consists of eleven segments. Terminal segment of the abdomen bears cerci or forceps. Malpighian tubules are usually absent. The examples are *Campodea*, *Heterojapyx*.

Super Order Ectognatha

Mandibles and maxillae are not covered by the lateral fusion of labium and cranium.

Order *Thysanura*. Abdomen consists of eleven segments. Rudimentary appendages may occur in some abdominal segments.

The last segment or anal segment has two or three many-jointed anal cerci. Malpighian tubules and compound eyes are usually present. The examples are *Lepisma* (silver fish), *Machilis*.

Subclass Pterygota

Adults possess wings which may be secondarily lost. Excepting cerci, other appendages are absent in the abdomen. Malpighian tubules are present. Metamorphosis may be complete or incomplete. This large subclass is subdivided into four sections—Paleoptera, Polyneoptera, Oligoneoptera and Paraneoptera.

Section Paleoptera

At the time of rest, the wings cannot be placed parallel to the abdomen. Surface of the wing is thickened only in correlation with veins. Wings originate as external buds. Malpighian tubules are many. Two living orders—Ephemeroptera and Odonata are included under this section.

Order *Ephemeroptera*. The members of this order are called the mayflies. Adults are aerial but larvae are aquatic. Mouth parts are degenerated in adults. Wings are not of same size, the hind wings are degenerated. Wings appear in the last immature stage and is followed by ecdysis. This is the only winged insect where ecdysis occurs after the appearance of wings. Terminal part of the abdomen bears two elongated cerci and a median filament. The examples are *Ephemera*, *Hexagenia*.

Order *Odonata*. Dragon flies and Damsel flies. All the insects are of large size. Two pairs of almost equal wings. At rest the wings are either held unfolded or extended laterally. Rudimentary antennae are present. Mouth parts are adapted for biting. The eyes are very big and conspicuous. Larvae are fully aquatic. The well-known examples are *Anax*, *Aeschna*, *Ischnura* and *Lestes*.

Section Polyneoptera

Wings are provided with rich supplies of veins. At the time of rest, the wings are always kept folded over the abdomen. Numerous Malpighian tubules are present. This section includes nine orders which are given below:

Order *Dictyoptera*. Cockroaches and Preying mantids are the representatives of this order. These insects usually run. Mouth parts are of primitive condition and used for biting. Cerci are jointed. Tarsi composed of five segments. Eggs remain within a capsule called *ootheca*. The examples are *Periplaneta*, *Mantis*.

Order *Isoptera*. The order is exemplified by the white ants or termites. They exhibit polymorphism. Females have much enlarged abdomen. In winged forms, the wings are of same sizes and can be separated at will. Each wing has a longitudinal venation and chitinised network in between. Mouth parts are adapted for biting. The example is *Termes*.

Order *Zoraptera*. Size is extremely small. They exhibit polymorphism. Males are usually without wings. Tarsi have two joints. The example is *Zorotypus*.

Order *Plecoptera*. The order includes the stone flies. Antenna is long. Cerci are distinct. Larva is aquatic. In course of development a terrestrial stage appears which contains, only wing buds. Winged forms develop from this stage and become aerial. The examples are *Perla*, *Isoperla*.

Order *Notoptera*. Wings are absent. Larva resembles the adult in all structural details. The example is *Grylloblatta*.

Order *Cheleutoptera*. Some are wingless, whereas others may have wings. All the members exhibit structural features to mimic either leaves or branches of the tree. Winged forms exhibit gradual appearance of various structures from larva to the adult. But in wingless forms the larva resembles the adult in all structural details. The eggs resemble the structures of seeds. The examples are *Carausius* (stick-insect), *Phyllium* (leaf-insect).

Order *Orthoptera*. Grasshoppers, locusts and different crickets are the representatives of this order. Structure of head resembles that of cockroach. Legs of the metathoracic segment are adapted for jumping. A well-developed ovipositor is present. Mouth parts are of biting type. The examples are *Hieroglyphus*, *Tryxalis*, *Locusta*, *Schistocerca*, *Gryllotalpa* (mole cricket).

Order *Embioptera*. The members of this order are the web-spinners. Size is small. Tarsi are three-jointed. Possess silk glands to form silken tunnels for living. The example is *Embia*.

Order *Dermaptera*. Ear-wings are the members of this order. Anterior wings are short. Posterior wings are papery and have radially arranged veins on its surface. Posterior wings may be folded both transversely and longitudinally. Mouth parts are adapted for biting. Anal cerci are like forceps. The example is *Forficula*.

Section Oligoneoptera

Metamorphosis is complete. Jugal area of the wing contains only one vein. Limited number of Malpighian tubules are present. Wings always develop from inner wing buds. Mouth parts are adapted either for biting or for sucking. It includes following eleven orders:

Order *Coleoptera*. The members of this order include the beetles. Prothorax is freely movable. Posterior pair of wing is membranous. Anterior pair of wing is stiff and covers the folded posterior wing during rest. Well-developed jaws are built up for biting and chewing. Metamorphosis is complete. Larvae may be maggot-like or caterpillar-like. No special covering is present around pupa. The examples are *Photinus*, *Calandra*, *Adalia* and *Dineutus*.

Order *Megaloptera*. Mouth parts are adapted for biting. At the margin of the wing, the longitudinal veins exhibit sign of bifurcation. Metamorphosis is complete and the larvae are aquatic. The examples are *Sialis* (Alder-flies), *Corydalis* (Dobson-flies).

Order *Raphidioptera*. The snake-flies are the members of this order. Prothorax is long. Head is narrow. Metamorphosis is complete. Larvae and pupae are all terrestrial. The example is *Raphidia*.

Order *Planipennia*. Mouth parts adapted for biting in the adult but sucking in the larva. In the late larval stage, Malpighian tubules are modified to secrete silk which is used in the formation of a cocoon. The examples are *Mantispa*, *Myrmeleon* (Ant-lion).

Order *Mecoptera*. The members of the order are the Scorpion-flies. Abdomen in male is curved upwards. Head bears a beak-like prolongation and mouth parts are present at the tip of this beak. Wings are membranous and all alike. The example is *Panorpa*.

Order *Trichoptera*. Caddis-flies are the common representatives of the order. Wings are hairy, membranous and are of dissimilar sizes. At rest the wings remain as a roof-like peak. Mandibles are generally absent. Mouth parts are specialised for licking. Larvae are aquatic and produce silken case within which they reside. The examples are *Rhyacophilia*, *Mayatrichia*.

Order *Lepidoptera*. All the butterflies and moths belong to this order. Broad and well-developed wings are enclosed by scales which are modified hairs. Wings are generally oriented with varied specks of colours. Maxillae in adults are modified into a spirally-coiled sucking tube. Remaining mouth parts excepting the labial palps are lacking. First two divisions of the thorax are fused. Metamorphosis is complete. Larvae possess three thoracic feet and in some cases several abdominal legs may be present. Mouth parts of larvae are modified for biting. Pupa is always covered with a case. The examples are *Pieris*, *Samia*, *Venesa*, *Teinopalpus*, *Papilio*, *Parides* and *Bombyx*.

Order *Diptera*. Flies and mosquitoes belong to this order. Metathoracic wings are modified as the *halteres*, which act as balancers. Mesothoracic wings are well-developed but with sparse venation. Mouth parts may be adapted for piercing and sucking or only sucking. Metamorphosis is complete. The examples are *Anopheles*, *Culex* *Musca*, etc.

Order *Siphonaptera*. External parasites on warm-blooded animals. Wings are absent in adults. Coxae of the legs are exceedingly large. The examples are the fleas represented by the genera, *Pulex*, *Ctenocephalus*, etc..

Order *Hymenoptera*. Wings are membranous. Two pairs of wings remain interlocked by hooks on the anterior border of hind wing. The appendages around mouth are arranged for biting, licking and sucking. All the thoracic segments are united and the first abdominal segment is fused with it. Polymorphism occurs in certain forms. Metamorphosis is complete. Development is complicated and larvae are helpless. Pupa is covered by a cocoon. The well-known examples are *Apis* (Honey bee), *Vespa* (Wasp), *Formica* (Ant).

Order *Strepsiptera*. Wingless and degenerated females are endoparasites but the males are free-living and winged. Anterior wings in males work as halters. At rest the hind wings of male remain folded like fan. Metamorphosis is complete. The example is *Stylops*.

Section Paraneoptera

Wings develop from external wing buds. Wings are usually poorly developed. Very limited Malpighian tubules are present. Metamorphosis varies from partially complete to fully complete condition. Mouth parts are adapted for either biting or sucking. All the forms are either parasites or pests and are included within the orders—Psocoptera, Mallophaga, Anoplura, Thysanoptera, Homoptera and Heteroptera.

Order *Psocoptera*. Book lice are the members of the order. Size is extremely small. Wings may or may not occur. When present, the anterior pair is larger and both are membranous. Cerci are absent. Mouth parts are built up for biting. The example is *Psocus*.

Order *Mallophaga*. This order includes the bird lice. Body is dorso-ventrally flattened. Antennae are short. Wings are absent. Mouth parts are degenerated but adapted for biting. Youngs resemble the adults in structural details. The example is *Menopon*.

Order *Anoplura*. The order includes the sucking lice. All are ectoparasites of mammals. Mouth parts are adapted for piercing and sucking. Wings are absent. Body is dorso-ventrally flattened. The example is *Pediculus*.

Order *Thysanoptera*. All thrips are the examples. All are plant pests. Mouth parts are adapted for sucking. Wings may or may not be present. When present the wings are slender and with elongated setae at the margin. The example is *Heliothrips*.

Order *Homoptera*. Mouth parts are adapted for sucking. Pronotum is rudimentary. Wings are membranous and during rest are held in roof-like fashion. The examples are *Aphis*, *Cicada* and *Tachardia* (Lac insect).

Order *Heteroptera*. Mouth parts are sucking. Pronotum is large. Wings, at the time of rest, lie one over the other. Mesothoracic wings are thick and its lower half is pigmented. The examples are *Cimex*, *Anasa*.

THE ONYCHOPHORES

Commonly known as velvet worms or Peripatus. Body is worm-like. Head is not clearly differentiated. Externally the segmentation is denoted only by the presence of short paired stumpy legs. Jaws are modified locomotory appendages. Eyes are more like those of annelids. Integument is very thin and the cuticle contains varied ring-like striations. Muscles are unstriated. Respiration is carried by both coxal vesicles and tracheal tubes. Spiracles are without any closing device. Excretory organs are paired segmental coelomoducts. All are carnivorous. Fertilization is internal. Usually viviparous. Reproductive and excretory ducts are ciliated. There are twelve genera of the onychophora.

THE TARDIGRADES

These small aquatic animals are commonly called water-bears. Size never exceeds more than 1·2 mm in length. It can survive prolonged dryness. Body is poorly demarcated into head and trunk. Four segments of the trunk are represented by four pairs of wart-like legs. Each leg has four claws. Cuticle is without chitin. Usually herbivorous. Mouth parts are modified for piercing and sucking. Excretion is carried by three small glands which open into the cavity of the gut. Fertilization is usually internal. All are oviparous. Two kinds of eggs are released. In an individual, the number of cells is always constant, thus the growth after certain period involves only the elongation of cells. The examples are *Macrobiotus*, *Hypsibius*.

THE PENTASTOMIDS

All the members are parasitic and popularly known as Tongue worms. Adult lives within the nasal passage of dog and other animals including man. Different structures are degenerated in the adult. Females are 10 cm in length. Larva possesses 2–3 pairs of unjointed legs. Cuticle contains chitin and exhibits annular markings in the adult. Muscles are striated. Completion of life history requires intermediate host. The examples are *Linguatula*, *Armillifer*.

GENERAL NOTES ON ARTHROPODA

This large phylum includes nearly 9,00,000 species. All of them possess a few common characters, but at the same time they exhibit diversity. The arthropods, discussed as types, have clearly exemplified that in habit, form and structure, these animals show great diversity. Attainment of such a diversity has enabled them to explore all possible ecological niches. The study of arthropods is important to understand the major principles of biology and at the same time for the immense economic importance of some of the groups.

HISTORY

The earliest record of the study of arthropods is available from the work of Aristotle (384–322 B.C.), who coined the term Malacostraca to include crabs and the related forms. The present trend of studying Arthropoda began with the work of Linnaeus (1707–1778), who created a group *Insecta aptera* to include Crustaceans, Myriapods and Spiders. The names Crustacea and Myriapoda were first introduced by Cuvier (1769–1832) and Latreille (1825). Lamarck (1744–1829), in his classification, included spiders, mites, myriapods and silver fishes under Arachnida and grouped prawns, lobsters, crabs and water fleas within Crustacea. It was Cuvier who first suggested to include these animals and Annelids under one large group, *Articulata*. Von Siebold (1845) later separated the Annelids and the rest were included under *Arthropoda*.

HABIT AND HABITAT

The arthropods are seen from 30,000 feet below to 20,000 feet above the sea level. These bilaterally symmetrical, jointed-leg invertebrates may be marine, freshwater, terrestrial, subterranean and aerial. Some arthropods like barnacles, are sedentary. Innumerable crustaceans which live as planktons, move passively in the current of water. But well-developed structures are present in many arthropods for moving effectively by swimming, crawling and flying. Some arthropods live within burrows, some are efficient diggers and many others build well-designed nests. Certain arthropods like honey bees, ants and termites are polymorphic and lead a complicated social life. All the food habits—herbivorous, carnivorous and omnivorous are seen among arthropods and various food-getting devices are met within this group. Large number of arthropods live as parasites and structural changes occur in them to adjust with the peculiar mode of life. Many arthropods are well-known for their habit of migration. Some of them can produce sound and nearly all are equipped with efficient sense organs. Some forms exhibit a phenomenon—*suspended animation*, to overcome unfavourable conditions. Sexual reproduction is often accompanied by courtship dances. The members may either be oviparous or viviparous or ovoviviparous and some forms exhibit parental care. Parthenogenesis is quite common in arthropods.

TAGMATIZATION

The metamerically segmented body of arthropods shows distinct advancement over annelids in having prominent specialisation of regions. Each structurally and functionally differentiated region contains several segments and is called a *tagma*. Such regionalisation is known as *tagmatization*. It often involves fusion and condensation of segments and the pattern varies in different arthropods. The crustaceans have three tagmata—*head*, *thorax* and *abdomen*. But in different crustaceans the arrangement of segments in the three tagmata may vary. In the Myriapods, the anteriormost tagma, *head* is well defined but the other two tagmata, *thorax* and *abdomen*, are not defined. For this reason the posterior part of the body after the head is called *trunk*. All Chelicerates exhibit extreme condensation of the body. Here, an anterior *cephalothorax* is formed by the fusion of the head and thoracic segments and a posterior *abdomen* with or without external segmentation. Among the arthropods, the tagmatization is most perfect in insects, where *head*, *thorax* and *abdomen* have been fully differentiated. This attainment has probably enabled the insects to radiate more efficiently than other arthropods. Compared to the arthropods, the pararthropods exhibit very little tagmatization. Only the Onychophores have the beginning of head formation.

Head

In **Crustacea**, the head is formed by the fusion of six segments. The organisation

of head varies in different Crustaceans. In Cephalocarida and Branchiopoda, the head is free from thorax. In free-living Copepods, only the first thoracic segment unites with the head to form a cephalothorax. Similar condition is seen in Syncarids, Amphipods and Isopods. In Tanaidacea, the first two thoracic segments unite with the head. All thoracic segments take part in the formation of cephalothorax in the Decapods. An exoskeletal covering, *carapace*, is usually present over the cephalothorax. The carapace is absent in Syncarids, Isopods and Amphipods. In Cirripeds, it forms a mantle with outer calcareous plates. The carapace extends only up to the second thoracic segment in Tanaidacea and Hoplocarids, up to the third thoracic segment in Cumacea and up to the fourth abdominal segment in Leptostraca and up to all cephalothoracic segments in Eucarida. In Phyllocarida, it encloses both the cephalothorax and abdomen.

In **Myriapods,** a distinct head capsule is formed. In Chilopods and Symphyla, the last segment of the head bears the second maxillae which unite to form the *labium*. But in Pauropoda and Diplopoda this segment becomes a part of the trunk and forms a structure called *collum*.

In **Insects,** the head is formed by the fusion of pre-antennal part and following five segments—*antennal*, *intercalary*, *mandibular*, *maxillary* and *labial*. The head is largely modified in different insects, but in all of them it occupies similar position and is bounded by following exoskeletal pieces —dorsal *epicranium*, lateral *genae* and frontal *clypeus*. Behind the epicranium there are two more pieces—*occipital* and *post-occipital* which border an opening, *foramen magnum*, at the posterior end.

In **Chelicerates,** the *head* is fused with the *thorax* to form *cephalothorax*. The only exception is the Solifugids, where the two are separate. In Pseudoscorpionidae, the cephalothorax is marked by two transverse grooves. In the Ricinulei, cephalothorax is drawn into an anterior projection called *cucullus*. In all the members, an exoskeletal covering, *carapace* covers the cephalothorax. The carapace is broad and strongly developed in the Xiphosurida.

Thorax

The thorax may be reduced in certain **Crustaceans** like Cladocera or unsegmented and enclosed within the carapace like Ostracoda. In free-swimming Copepods, only the first thoracic segment is indistinct and the last thoracic segment of the female is fused with the first abdominal segment. In all the parasitic and sedentaric forms like Copepods, Rhizocephala and Cirripeds, the thorax is degenerated. In Malacostraca, the thorax has eight segments and either all or some of them take part in the formation of cephalothorax.

In **Myriapods,** the thorax is not differentiated and in all Chelicerates (excepting the Solifugids) the thorax is intimately connected with the head to form cephalothorax.

In **Insects,** the thorax is distinct and consists of three segments—prothorax, mesothorax and metathorax. In most forms these three segments are firmly united.

Abdomen

In **Crustaceans,** the abdomen may be of various shapes. It is turned downwards and carries a pair of brood pouches in the female Cladocera. The abdomen is four segmented in free-swimming Copepods and bears a pair of caudal styles in the last segment. The number of abdominal segments varies in Malacostraca—six segments in Decapoda, Amphipoda and Isopoda, seven segments in Leptostraca and many in Stomatopoda. In Decapods and Isopods, the abdominal segments are free but fused in Amphipoda. The abdomen in crab is much reduced and pressed along the ventral wall of the cephalothorax. In Stomatopoda, the abdomen is longer than the cephalothorax. A telson with paired caudal styles is present in all excepting Syncarids where the caudal style is absent.

In **Myriapods,** the abdomen is not differentiated from the thorax.

In **Chelicerates,** the abdomen is distinct in most cases and shows the sign of further subdivision. In Xiphosura, the abdomen consists of six *mesosomal* segments and a vestigial *metasoma*. It is followed by a long and pointed *telson*. In Scorpionids, the mesosoma is broad and seven segmented but the metasoma is five segmented, long and narrow. The number of segments is ten in Solifugids and Opiliones. In Uropygi the abdominal segments are twelve. The eleven segments in the broad abdomen of Pseudoscorpionids are

not separated into mesosoma and metasoma. In Ricinulei, the nine segments are fused in such a way that only four are distinctly visible. The fusion is more intimate in Araneids, where only faint lines are visible in the soft and compact abdomen. A many-jointed flagellum is seen in Palpigradida and Uropygi.

In **Insects,** the abdomen is made up of eleven segments. In certain forms the abdominal segments exhibit fusion. The posterior abdominal segments are often modified to form genital chambers.

Appendages and non-appendicular structures

In Arthropods, each metamere contains a pair of appendages. Due to tagmatization, these appendages are often found to be shifted. Also in different forms the appendages are variously modified according to their functions (Figs. 16.119 and 16.120). In general, the arthropod appendages are made up of several articles or segments and the body cavity extends within the appendage.

In **Crustacea,** the appendages may be classified into three groups—*Cephalic, Thoracic* and *Abdominal appendages.*

Cephalic appendages include a pair of *antennules* or *first antennae*, a pair of *second antennae*, a pair of *mandibles* and two pairs of *maxillae*. (*i*) *Antennule.* This is well developed in Ostracoda, Copepoda and Malacostraca, but small in Cladocera and extremely minute in Cirripedia. It serves as locomotory organ in Copepods where the males also use it as clasping organ. It is uniramous in Tanaidacea, Isopoda and Amphipoda. It usually bears two flagella, but in Stomatopoda the number of flagella is three. (*ii*) *Second antenna.* It is large in Branchiopoda, Cladocera, Ostracoda and Malacostraca. In free-swimming Copepods it is small and uniramous and totally absent in Rhizocephala. In addition to its sensory function, it may be variously modified in different crustaceans. In parasitic Copepods, it is modified as a hook for adhesion and in some forms for absorbing nutrition. In Branchiopods, it works as prehensile organ and in Cladocera it is responsible for locomotion. (*iii*) *Mandible.* It is well formed in Cladocera, Ostracoda and Malacostraca. In the first two groups, the mandible contains a leg-like palp and a flagellum-like brush. In Malacostraca, the mandibles are with serrated-cutting edges which border the two sides of the mouth

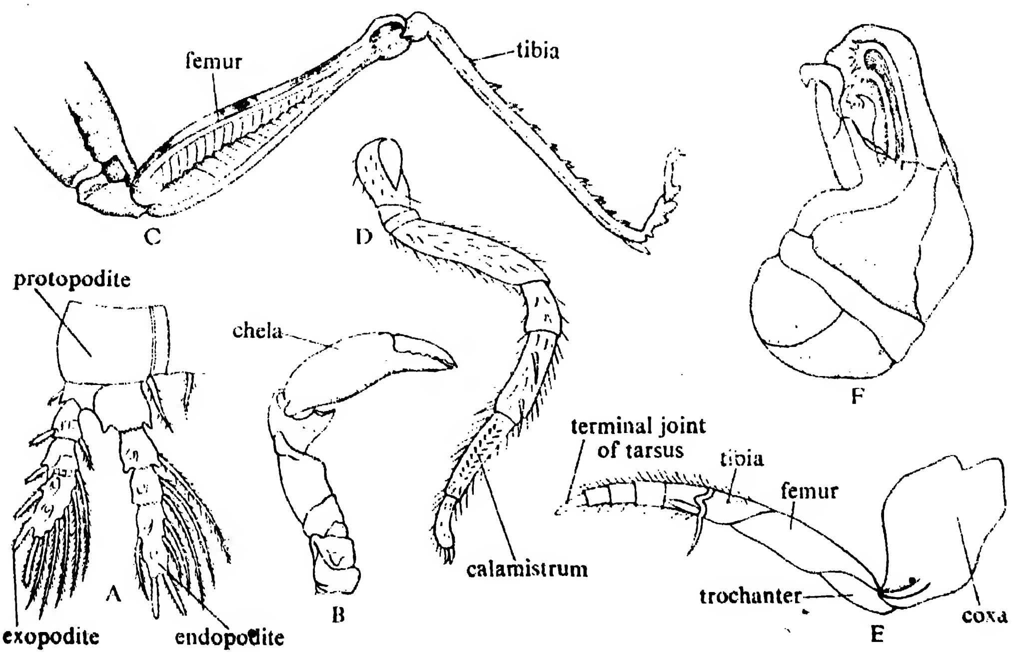


Fig. 16.119. Some interesting appendages of arthropods. A. Swimming legs of *Cyclops*. B. First leg of crab. C. Leg of locust. D. Leg of spider. E. Swimming leg of water beetle. F. Gonopod of Milliped.

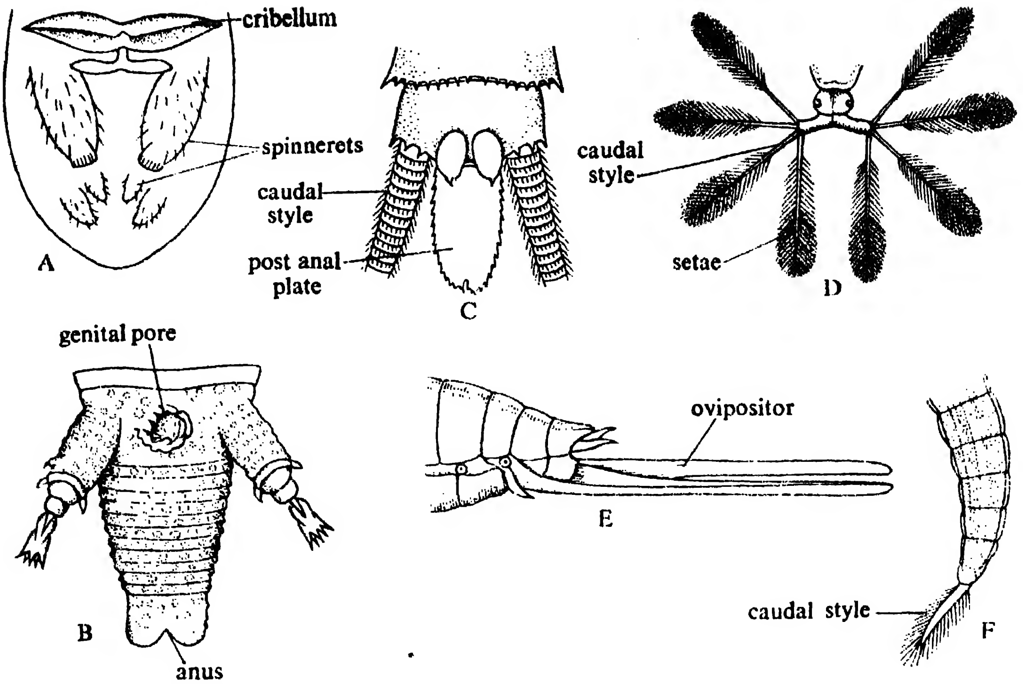


Fig. 16.120. Terminal end of abdomen in a few arthropods. A. Spider. B. Peripatus. C. *Lepidurus*. D. *Calocalanus*. E. Grasshopper. F. *Branchipus*.

and a long palp to assist in ingestion. (*iv*) *Maxillae*. Two pairs of maxillae follow the mandible. The first maxilla carries a large plate in Ostracoda. The second maxilla is absent in Cladocera and in Ostracoda it is jaw- or leg-like. In Malacostraca, the exopodite of the second antenna works as foot-cleaner.

Thoracic appendages vary in number among the crustaceans. The number ranges from 2–4 pairs in Ostracoda, 5 pairs in Cladocera and free-swimming Copepods to 8 pairs in Malacostraca. In Cladocera these are swimming appendages. In Ostracoda these appear as narrow legs. In free-swimming Copepods, the first four pairs are biramous swimming feet but the fifth pair is vestigial limbs. Extreme variations are noted in Malacostraca. In Mysidacea, all the thoracic appendages are alike, but in forms like Cumacea, Tanaidacea, Decapoda and Stomatopoda some of the anterior thoracic appendages are differentiated as maxillipeds and the posterior groups become walking legs. The maxillipeds are one pair in Tanaidacea, two pairs in Cumacea, three pairs in Decapoda and five pairs in Stomatopoda. Thus the walking legs in these groups are 7, 6, 5 and 3 pairs respectively. In Syncarida, slender respiratory exopodite and double series of epipodites are in association with thoracic appendages. The Mysidacea bears only exopodites.

Abdominal appendages are absent in Cladocera, Ostracods and Copepoda. Diverse arrangements are seen in Malacostraca. In Leptostraca, the first four pairs are biramous swimming feet and the last two pairs are uniramous and insignificant. The last pair in Syncarida together with telson constitute, a fan-shaped uropod. The first five pairs in males Mysidacea are larger than those of females. In Amphipoda, the first three are biramous swimming appendages but the last three are modified for jumping. First few in Isopoda and first five abdominal appendages in Stomatopoda carry the gills and in both the last pair form the uropods. Well-developed uropods are seen in Decapods like prawn and lobsters, but is absent in true crabs.

In **Myriapods**, the appendages are classified into two groups—*cephalic* and *trunk appendages*. Following appendages are present in the Cephalic region—*antennae*, *mandibles* and *maxillae*. (*i*) *Antennae*—In

most cases, one pair of elongated and many-jointed antennae are present. In Pauropods, the antennae are branched. (*ii*) *Mandibles.* These paired structures are used for cutting the food. Here, the mandibles are without palp. (*iii*) *Maxillae.* In Chilpods and Symphyla, the maxillae are two pairs and the second maxillae unite to form the labium. In Pauropoda and Diplopoda, the second maxillae are absent.

TRUNK APPENDAGES are represented by the *legs*. In Chilopoda and Symphyla, each trunk segment is provided with a pair of jointed legs. The legs of the first segment are directed anteriorly and through its terminal end opens the duct of the poison gland. It is known as *poison jaws* or *maxillipeds*. In Diplopods, each segment after the first four possesses two pairs of legs. The legs of the seventh segment are modified in male as copulatory organs.

In **Chelicerates,** the appendages are *cephalothoracic* and *abdominal*. Three types of appendages are found in the CEPHALOTHORAX—(*i*) *Chelicerae*, (*ii*) *Pedipalpi* and (*iii*) *Walking legs*.

(*i*) *Chelicerae*. It is the appendage of first postoral segment, but it occupies preoral position. In Scorpionids, it is small and composed of three articles. The distal articles are chelated. It is two-jointed and hook-like in Amblypygi. Number of articles vary in Acarida from 2–6 and this appendage may be pincer-like, fang-like or lance-like. The chelicerae contain silk glands in Pseudoscorpionids and poison glands open through them in Araneida. It is quite prominent in Palpigradi, Ricinulei and Solifugae. (*ii*) *Pedipalpi*. It represents the second postoral segment. In Xiphosurida, it is leg-like, jointed and helps both in food capture and locomotion. Here the proximal segment is spiny and the distal part is chelate. In Scorpionida, Araneida and Pseudoscorpionids, the pedipalp is made up of six articles. It is leg-like in Palpigradi, Solifugae and Opiliones. In Uropygi, it is small, stout and its base, together with the upper lip of the rostrum, forms a ball and socket-joint around the mouth to act as filtering apparatus. In Amblypygi, each pedipalp is seven segmented and is raptorial in function. It contains poison gland in Pseudoscorpionids and in Acarida it may be variously modified. In male Araneida, the tip of the pedipalp is modified for sperm transfer. (*iii*) *Walking legs*. In the Xiphosurida, the third to sixth pairs of appendages are the walking legs. The legs exhibit sexual dimorphism. In addition to their function of locomotion the legs are adapted for ingestion. For this purpose, the bases of the legs are drawn into spiny lobes called gnathobases. All the legs excepting the last are chelated. The last leg bears four movable spines at the distal tip to act as shovel and a *spatulate process* in the outer border of its base. In addition to the walking legs, the cephalothorax of Xiphosurids bears a pair of small flat appendages called *chillaria*. All Arachnids contain four pairs of legs. In Acarida, the legs are clawed at the distal tips. In Opiliones the legs are very long and slender. In Uropygi and Palpigradi, the second pair of legs is long and antenna-like.

ABDOMINAL APPENDAGES in the Chelicerates usually do not take part in locomotion. The Xiphosurida contains six pairs of abdominal appendages on the ventral side of the abdomen. Each lamellar appendage carries a slender inner process and a broad outer plate. First pair are fused in the middle to form a *genital operculum*. The remaining pairs are free and each carries a gill. In Arachnids, the abdominal appendages appear as rudiments during embryonic development. But in adults these are transformed into various structures like *pectines* in Scorpionids and *spinnerets* in Araneida. The respiratory organs, *book lungs* are also formed as the appendage-buds near the posterior end of the abdomen of the embryo. The *caudal spine* of Xiphosurids is regarded as the appendage of the telson and the *poison gland* and *sting* of Scorpionids are formed by the transformation of the *telson*.

In **Insects,** various structures are grouped as *cephalic*, *thoracic* and *abdominal* ones. The cephalic region includes (*i*) *Antennae* and (*ii*) *Mouth parts*. The thoracic region contains locomotor structures—(*i*) *Legs* and (*ii*) *Wings*. The abdomen in adults do not have any paired appendage, but various structures like *stings*, *ovipositors*, *genital processes*, etc. are seen to be present in the abdomen. The *eye* is often considered as an appendage of pre-antennal

segment. The *wings* and other unjointed structures having no supply of blood, nerve and muscles are regarded as non-appendicular structures.

Structures in the head of insects

ANTENNAE. These paired appendages work at tactile, olfactory, vibration-receptive and proprioceptive organs. They may be of various shapes—bristle-like (*Locusta*), moniliform (*Tenebrio*), club-shaped (*Slipha*), pectinate (*Ctenicera*) and lamellated (*Melolontha*).

MOUTH PARTS. In addition to the appendicular parts like *mandibles* and *maxillae*, two non-appendicular structures take part in the formation of mouth parts (Fig. 16.121). These are called *hypopharynx* and *labrum*. The hypopharynx is the extended part of a process which originates centrally from the posterior wall of the mouth. The hypopharynx together with the frontal (*clypeus*) and ventral (*labrum*) exoskeletal plates in the head form a cavity in front of the mouth. This space is called *cibarium* and it is internally lined by a highly sensory membrane. The labrum remains movably articulated with the lower border of clypeus and acts as upper lip. The basic parts are the same in all insects but the architecture varies widely and depends upon the feeding habit of the particular group. In Orthoptera and Coleoptera the mouth parts are like those of cockroaches adapted for biting and chewing. In Hymenoptera, these are modified for piercing and sucking. Here, the mandibles and the first maxillae are sharply pointed and the labium is drawn into an elongated tongue with accessory branches or *paraglossae* on its lateral sides. In Hemiptera, labium encloses the elongated mandibles and maxillae to form a *proboscis*. In the females of some Diptera the mouth parts are adapted for piercing and sucking. The mandible forms the piercing structure and on its ventral side the labium forms the *proboscis sheath* to enclose six needle-shaped *piercing styles*. The structures, like *labrum-epipharynx* and *hypopharynx* together with proboscis sheath form a sucking tube.

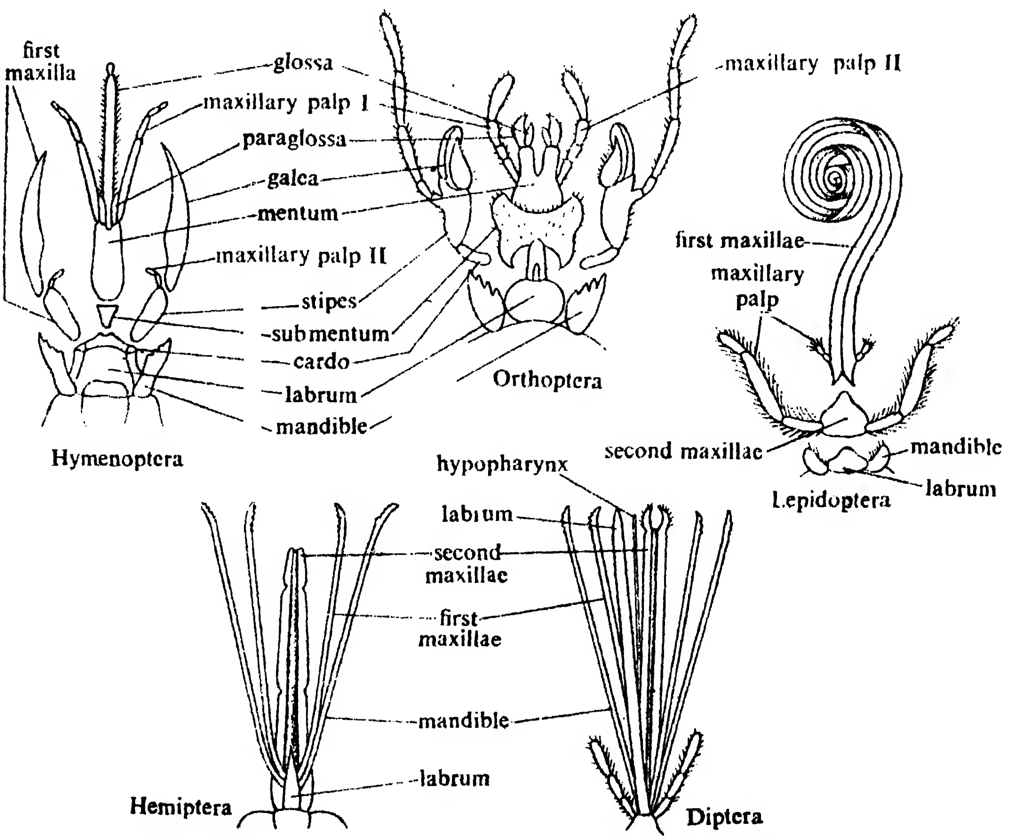


Fig. 16.121. Enlarged view of mouth parts in a few types of insects (diagrammatic).

In Lepidoptera, the mandibles are reduced in the adult. The two maxillae extend to form a long tube which remains coiled beneath the head.

Structures in the thorax of insects

LEG. Each segment of the thorax bears a pair of legs. Each leg has five articles—*coxa*, *trochanter*, *femur*, *tibia* and *tarsus*. The distal segment may have either pad or sucking disc or single or paired claws. The shape of the leg varies according to the habit of the insect. In walking insects, the legs are slender and in jumping insects the metathoracic legs are long and powerful. The aquatic insects have flattened and paddle-like legs. In the honey bee, functional differentiation among the legs is distinct.

WINGS. The wings are not appendages, these are extensions of the body wall. In general, the insects possess one pair of wings on the mesothorax and the other pair on the metathorax. The wings develop as *wing buds* which may be either internal or external. Each wing is supported by an arrangement of branching ribs, called *nervures*. Each rib carries the branches of tracheae, which remain functional up to the completion of the development of wing. The shape, pattern and number of wings differ in various insects. In Lepidoptera, both the wings are large and are covered by numerous brilliantly coloured scales. In beetles, the anterior part is hard and known as *elytra*. At the time of rest, it covers the membranous metathoracic wings. In Diptera, the anterior pair are well-developed but the posterior pair are shortened and known as the *halteres* or *balancers*. In the Strepsiptera, the anterior wings are halteres and posterior wings are well-developed. In the bee-parasites, the anterior pair are vestigial and the posterior pair are membranous. The wings are entirely absent in lice and fleas.

Structures in the abdomen of insects

The paired appendages of the abdominal segments in the insects appear in the embryo but later either fail to develop or are transformed into some specialised structures. Following structures are usually seen in the abdomen of many adult insects—*vestigial legs*, *cerci* and *external genitalia*.
(1) VESTIGIAL LEGS. Larvae of pterygota bear functional appendages in the abdomen, e.g. caterpillar of Lepidoptera bears abdominal legs called *prolegs*. Neuroptera larvae possess gills on the abdominal appendages. But locomotor appendages are absent in the adult pterygotes. Three orders of Apterygota—Protura, Thysanura and Aptera carry some form of abdominal appendages. In Protura, the first three abdominal segments bear rudimentary paired appendages resembling thoracic legs. The double appendages of Aptera in the first seven abdominal segments may be either like projecting styli (*Anajapyx*) or like retractile vesicles (*Japyx*). In Thysanura, similar styli are present in the segments second to ninth and the retractile vesicles in the first seven segments of the abdomen. Three median unpaired appendages are present in the five segmented abdomen of Collembola. Each appendage is formed by the fusion of the two. In the first abdominal segment, the appendage forms a structure called *collophora*. In the fourth segment it becomes a spring-like *furcula* and in the third segment it forms a clasp called *tenaculum*.
(2) CERCI. These are the appendages of eleventh and last abdominal segments. Where the number of abdominal segments is reduced, it may also be shifted. It is small and scale-like in cockroach and grasshopper, but long and filiform in insects belonging to the Aptera, Thysanura and Ephemerida. In Dermaptera, it is modified as forceps-like structure.
(3) EXTERNAL GENITALIA. External genitalia in both the sexes are formed by the modifications of abdominal appendages and other non-appendicular parts. In the female, genitalia is concerned with the deposition of eggs and in males it assists in copulation. A number of insects possess *ovipositor* formed by the modification of appendages belonging to the eighth and ninth segments. In Thysanura, paired *styli* and *lobes* work together with four elongated *gonapophyses* to form the ovipositor. In Orthoptera, the ovipositor is formed by two *valvifers* and three *valvulae* of eighth and ninth abdominal segments. Such ovipositor is seen in most members of Phasmida, Dictyoptera, Grylloblatodea, Corrodentia and Odonata. Number of valvulae are two pairs in Dermaptera and Neuroptera. In Hemiptera and a few Mallophaga, it is further reduced to one pair. In Hymenoptera, all the three pairs are present but in stinging forms the entire ovipositor is modified into a *sting*. In Orthoptera, the ovipositor is modified for

digging. In males, the abdominal appendages take part in forming special structures around genitalia which is used for grasping the female genitalia at the time of copulation. It is present in Thysanura, Ephemerida, Grylloblattodea, Hemiptera, Mecoptera, Lepidoptera, Diptera, Neuroptera, Trichoptera, Hymenoptera and Siphonaptera. In all it is formed by the appendages of eighth and ninth abdominal segments. In Odonata, it is formed by the modifications of the appendages belonging to the third abdominal segment.

INTEGUMENTARY SYSTEM

In all arthropods, the integument consists of (*i*) an innermost extremely thin stellate cell layer, called *basement membrane*, (*ii*) a monolayer of closely packed hexagonal cells, *hypodermis* (*epidermis*) and (*iii*) outer non-cellular layer, *cuticle*. The cuticle is secreted by the hypodermis and excepting the regions of joints it is many-layered. The cuticle also lines the inner wall of fore gut, hind gut, trachea and genital atrium. The cuticle consists of two layers—outer *epicuticle* and inner *procuticle*. The cuticle is extremely thin and usually does not contain chitin (exceptions are a few Centipeds and Pycnogonids). Specially in insects, it has been seen to contain wax, lipids, proteins and steroids. The wax and lipids make it impermeable to water. The procuticle contains chitin, a special kind of polysaccharide and is divisible into two layers—*exocuticle* and *endocuticle*. The outer exocuticle is a tough layer and the inner endocuticle is many-layered and flexible. In Crustacea and Diplopods, various calcareous substances are seen to be deposited in the exocuticle. The different colouration of the pigments is due to the presence of pigment cells in the hypodermis. The outer part of the integument may have various striations and markings. Its outpushings may form spiny structures and inpushings give rise to apodemes for the attachment of muscles.

MUSCULAR SYSTEM

In arthropods, the muscles are striated. In the thorax the *longitudinal muscles* are present as a pair of dorsal and a pair of ventral bundles. Each joint is provided with two sets of muscles, one of which is antagonistic to the others. Some of these *somatic muscles* can work at astounding speed, e.g. wing muscles of insects, muscles operating the stridulating organs in various arthropods. The *splanchnic muscles* are present around the gut, heart, aorta, diaphragm, etc. These muscles are arranged either as layers of longitudinal and circular muscles or as myofibrilar network.

BODY CAVITY

In Arthropoda, true coelom appears as pouches in the embryonic stage. In course of development its walls are used up in the formation of organs and the space becomes continuous with the blastocoel. It is called *mixocoel* and as blood flows through it, this is also referred as *haemocoel*. In Crustacea, true coelom is restricted to the space of ophthalmic artery, within excretory and reproductive parts. Almost similar condition is found in Onychophores, where true coelom is restricted only around the excretory and reproductive parts. But in Myriapods and Insects, the coelomic spaces, are retained only in reproductive parts.

DIGESTIVE SYSTEM

The digestive system is concerned with *nutrition*. The process primarily involves three phases—*ingestion*, *digestion* and *egestion*. As arthropods live in varied habitats, they carry out these phases in different ways. Each group has developed the structures perfectly suited to its particular way of life.

The digestive system includes—(1) *Alimentary canal* and (2) *Digestive glands*. The digestive system is absent in certain adult insects, e.g. Mayflies and much modified in a few parasitic crustaceans like *Sacculina*.

Alimentary canal

In general the alimentary canal is divisible into three parts—(*a*) Fore gut, (*b*) Mid gut, and (*c*) Hind gut. The structure varies in different arthropods (Fig. 16.122), but in all the fore and hind guts are lined internally by cuticle.

CRUSTACEA. In parasitic Crustaceans, specially in endoparasites, the alimentary canal shows marked degeneration. But in free-living forms it extends along the entire length of the body. In most Crustaceans, the fore gut includes mouth, gullet and oesophagus. But in Malacostraca, the next part, stomach is also included within fore gut. The mouth in general is ventrally placed and some distance away from the

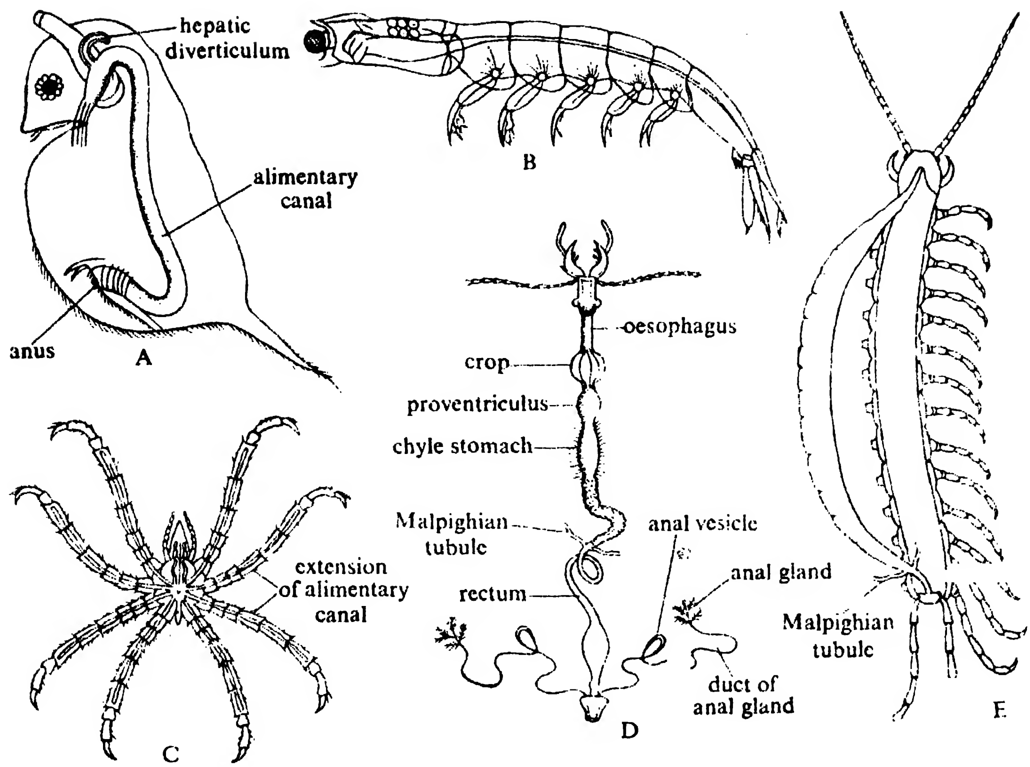


Fig. 16.122. Alimentary canal in a few arthropods (other structures of the body are not shown). A. *Daphnia*. B. *Euphausia* (Thoracic appendages are not drawn). C. Spider (*Ammothea*). D. Beetle (*Carabus*), Malpighian tubules are partly drawn. E. *Lithobius*, a Myriapod (Malpighian tubules are partly drawn).

anterior end. The gullet is vertical and the stomach is more or less sac-like. In most Crustaceans, the mid gut is straight and dorsally placed. The intestine is coiled in Cladocera. Near the posterior end of the mid gut in Amphipoda, single or paired caeca are present. The hind gut contains a bulb-like rectum which opens to the exterior through a posterior terminal aperture called anus.

Myriapods. Length of the fore gut varies in different Chilopods. In Diplopods, a preoral cavity is present in front of the mouth and it leads to a pharynx of varied length. The lining of mid gut in the same group contains both secretory and absorptive cells. The hind gut is considerably long and in some (Julidae) is subdivided into three parts. The last part is usually sac-like and eversible. In the Pauropoda, the fore gut is contractile and the mid gut begins from third segment of the trunk. The hind gut is divisible into a tubular part and a sac-like part. In Symphyla the hind gut is divisible into four parts.

Insects. *Mouth* is placed at the ventral and terminal end of the head. Mouth is bounded by mouth parts which differ according to the food habit of the insect. The other parts of the fore gut include a well-developed *pharynx*, bag-like *crop* and a muscular *gizzard* or *proventriculus*. The gizzard is prominent in Coleoptera and ants. In honey bee, it acts as a honey stomach. The mid gut varies widely in insects. The anterior end of the mid gut in most insects gives rise to *diverticulum* or *caecum*. The caecum is absent in Lepidoptera and Collembola. In some Diptera the mid gut is long, coiled and divisible into an *anterior digestive part* and a *posterior absorptive part*. In Heteroptera, the anterior part is sac-like and known as stomach, while the much coiled posterior part is called *intestine*. In Homoptera, the fore gut and hind gut join with each other and the mid gut is set aside as a loop. In Coccidae the last part

of the fore gut and the first part of the mid gut remain inside the hind gut. In most insects, a constriction separates the mid gut from hind gut and the latter is divisible into a slender anterior part and broad posterior part. In some Coleoptera and termites the hind gut is sac-like and contains cellulose-splitting bacteria.

CHELICERATES. The position of mouth varies. In Xiphosurids, the slit-like mouth lies in between the second and fifth gnathobases. A preoral cavity is present in front of the mouth of Scorpionids and Uropygi. In Palpigradi, mouth is present on the segment which bears pedipalp. In Ricinulei, the preoral cavity is covered anteriorly by a flap-like projection of carapace, called *cucullus*. A projected rostrum in Solifugae bears the mouth at its tip. Usually the pharynx and in some cases (spider) the stomach is suctorial. The mid gut sends paired and much branched diverticula in all chelicerates, where both digestion and absorption take place. Only unbranched diverticula are seen in Opiliones, Ricinulei and Acari. In Xiphosurids the diverticula fill up the prosoma but in Arachnids it is restricted only to the abdomen (excepting scorpion, where two pairs extend within prosoma). In Scorpionids, the hind gut is the straight continuation of the mid gut and is called rectum. In Xiphosura, the short tubular rectum has folded walls. In spider and Pseudoscorpionids, dorsal diverticula are given out from the rectum.

Digestive glands

In CRUSTACEA, the most important digestive gland is *hepatopancreas*. It contains two kinds of cells—hepatic and pancreatic. The gland is formed by numerous finger-like tubules. In prawns and crabs, the hepatopancreas is placed within the cephalothoracic cavity. But in Amphipoda and Isopoda it extends within the abdomen. In Stomatopoda, these digestive glands are arranged in ten metameric pairs. Salivary glands are known in certain forms.

Among the MYRIAPODS, four pairs of salivary glands are seen in Chilopoda and Diplopoda. But in Pauropoda the number are reduced to two pairs and in Symphyla there are only one pair of large salivery glands. In addition to the salivary glands, the cells present in the lining of mid gut are also responsible for producing digestive juices.

In INSECTA, three sets of glands—*labial glands*, *maxillary glands* and *mandibular glands* are often referred together as salivary glands, which secrete digestive juices. Labial glands are slender, elongated tubes in muscoid flies and paired sac-like structures with lining of secretory cells in mosquito. Labial glands of larval Lepidoptera work as silk glands. The maxillary glands are functional in the adult Protura and Collembola. Mandibular glands are present in most Apterygota and in Dictyoptera, Isoptera, Trichoptera and Hymenoptera. Of these three kinds of salivary glands, usually only one kind is functional and other two are degenerated. But it may be that two or all the three sets continue to be functional. In honey bee the labial glands work as wax glands, and the mandibular glands produce secretion to soften the pupal case. True salivary glands originating from the pharyngeal system open within the pharynx. The saliva, in addition to its enzymes, often contains anticoagulant. The digestive juices are also produced from the lining of the mid gut.

In CHELICERATES, the salivary function is carried by a pair of rostral glands and a pair of maxillary glands. The diverticula of the mid gut produce digestive juices.

Mechanism of digestive system

The CRUSTACEANS exhibit an evolutionary trend in the food-getting devices. Primitive crustaceans (Cephalocarida) use their identical appendages for locomotion and also for filtering food particles from the surrounding water. But in advanced groups the appendages are differentiated to capture food. The best example is prawn, where maxillae and maxillipeds, while producing water current for respiration, assist the food to enter into the mouth. Mandibles cut the food into pieces. Some of the walking legs being chelated can grab the food. The stomach is also modified for crushing the food and also to digest it. The MYRIAPODS have powerful mandibles for capturing and cutting the food. In this group, the hind gut exhibits special structural changes for preventing any loss of water. The organisation of mouth parts in INSECTS speaks about the advancement of this group over others regarding food procurement. The intestine and diverticula perform the breakdown and absorption of food efficiently to meet

the excess demand of energy. Among CHELICERATES only the Xiphosurids are capable of ingesting solid food. The Arachnids have devices by which the prey is predigested either by injecting enzymes or by taking it in a special preoral cavity. The partly digested liquid food is sucked inside the alimentary canal.

RESPIRATORY SYSTEM

The respiration involves the exchange of gases between the body and the environment. The oxygen from the surrounding medium enters within the body and carbon dioxide comes out of the body to the environment. Either entire surface or at least some parts of the body act as respiratory surface. If the animal is terrestrial, then the surface of exchange must remain moist. Usually the circulatory system carries oxygen from the respiratory surface to the different tissues and again returns carbon dioxide from the tissues to the respiratory surface for removal. Following *devices* are seen in the animal world to carry out respiration: (1) through the general surface of the body, (2) through specialised organs like gills, lungs, etc. From the physiological point of view the respiratory acts may fall into three *categories:* (1) Individual gets oxygen which remains dissolved in water. (2) Individual exchanges gases with the surrounding air. (3) Individual lives in water but breathes air. All these *devices* and *categories* are met with in arthropods (Fig. 16.123) and the climax is reached in the insects, where respiration is totally independent of circulatory system.

Respiratory organs in Arthropods. Among the arthropods -Branchiopoda, Cirripedia, Chironomous larvae and minute Arachnids respire through the general surface of the skin. In these forms exchange takes place by the physical process of diffusion. But most arthropods have specialised structures for *aquatic* and *aerial* respiration.

Aquatic respiration

GILLS. The gills are the respiratory organs of aquatic arthropods. These are best developed in Crustaceans. In other aquatic arthropods, special types of gills are often encountered. (*i*) *Origin of gills in Crustacea.* Gills originate as outpushings of the body wall. In Amphipoda, the gills are outgrowths of the thoracic limbs and in Isopods the endopodites of second and fifth pleopods are modified as gills. (*ii*) *Shape of gills in Crustacea.* A typical gill is crescent-shaped. It consists of a rod, on each side of which are arranged blade-like gill filaments. One end of each filament remains connected with the rod and blood vessels enter into it through this region. The other end of the filament is blind. (*iii*) *Types of gills in Crustacea.* According to its mode of attachment the gills may be of three types: (*a*) Podobranch—attached with the coxopodite of the thoracic appendage, (*b*) Arthrobranch—attached with the arthroidal membrane and (*c*) Pleurobranch—attached with the lateral wall of the thorax. (*iv*) *Number of gills in Crustacea.* Number vary in different groups. The Decapods which contain all the types of gills exhibit extreme variation—in the shrimp, *Lucifer*, gills are absent; penaeid shrimp has 24; *Homarus* has 20; Peacrab contains 6 gills. In *Palaemon*, the anterior gills are small and the size increases towards the posterior end.

Modification of gills in Arthropoda. The gills are variously modified in Crustaceans and other Arthropods. In Phyllocarida, broad epipodites of the thoracic appendages work as gills. Similar gills are seen in Cumacea. Gills are plate-like in Amphipoda and flattened in a Decapod, *Palinurus*. In Euphausiacea, the tufted podobranchs are not covered by carapace. The gills appear as a row of small branchial lamellae on each side of Cyprididae. In Phyllopoda, the leaf-like pleopods work as gills. Among the Crustaceans only Stomatopods and Isopods have abdominal gills.

In the aquatic larvae of many insects, a series of simple and divided external processes are attached to the abdominal segments. These are richly supplied with tracheae and are called the *tracheal gills*. In certain insect larvae the tracheae are replaced by the branching of blood vessels and are called the *blood gills*. In the nymphs of several insects the inner surface of rectum bears gills. These gills are called the *rectal gills*.

The most specialised gills are seen in Xiphosurids, where the abdominal appendages bear plate-like book gills. These gills are formed by the evagination of the posterior borders of opisthosoma in segments from ninth to thirteenth. Each gill contains nearly 150 lamellae, which look like the delicate leaves of a book.

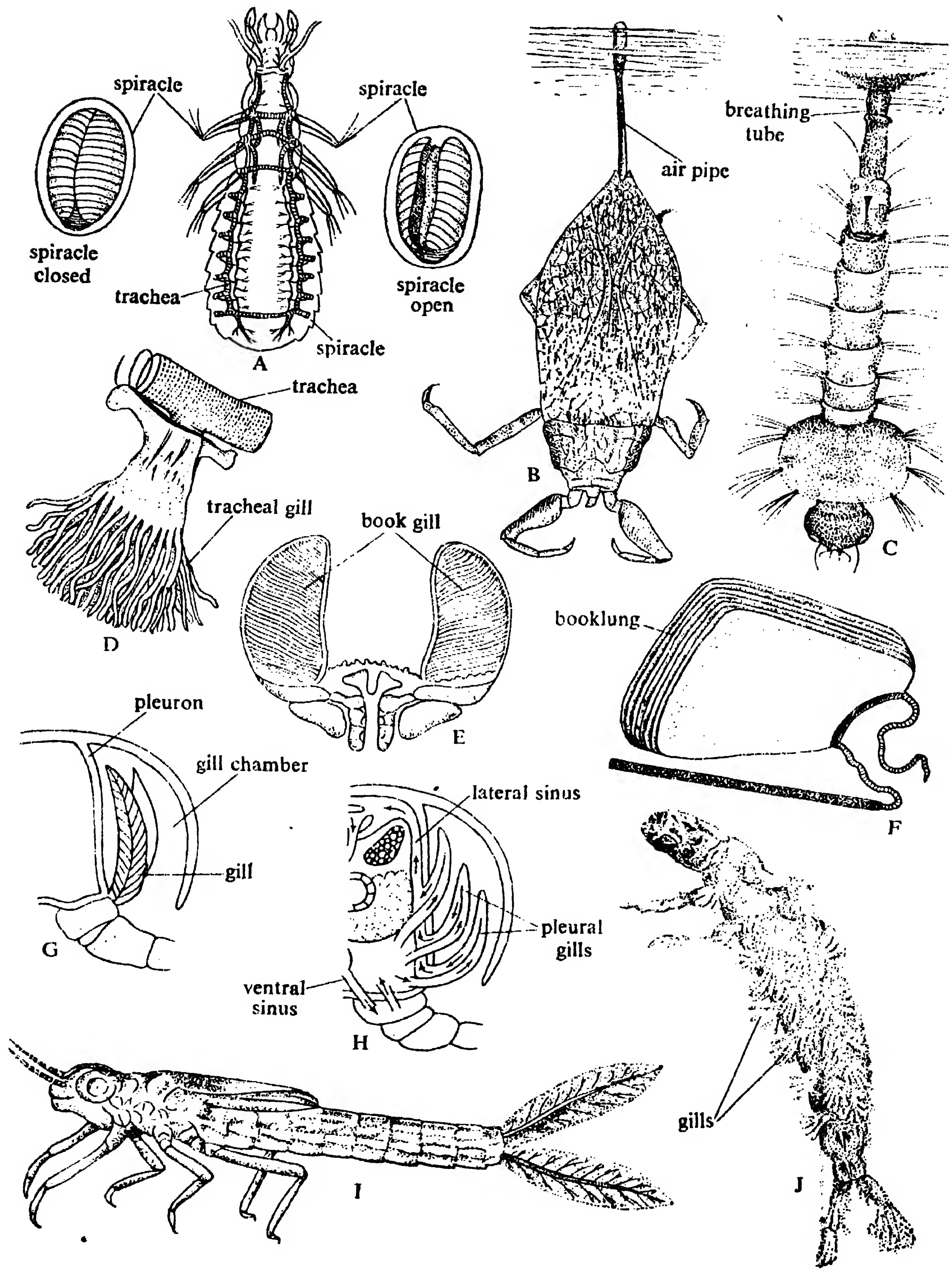


Fig. 16.123. Respiratory structures of a few arthropods. A. Tracheal system of a typical insect. B. Air pipe of water scorpion. C. Breathing tubes of a mosquito larva. D. Tracheal gill of an insect. E. Book gill of *Limulus*. F. Book lung of spider. G. Podobranchial gill of crustacea. H. Pleural gills of crustacea. I. Leaf-like gill of a damsel-fly nymph. J. Mesh of gills in a caddis-fly larva.

Mechanism of gill respiration. In most Crustaceans, the gills are not covered within a special gill chamber. But in Decapods, the carapace extends laterally over the gills to house them in a special chamber. In such forms with chamber, current of water enters through one end and after bathing the gills, passes out through another direction. In Crustaceans and Xiphosurids, in the gills gaseous exchange takes place between the blood and the water. But in Insects, after diffusion the oxygen passes to the tracheal tubes.

OTHER DEVICES OF AQUATIC RESPIRATION

In Crustacea, the *lining of the branchiostegite* and *epipodites* of thoracic appendages are often richly supplied with blood and act as respiratory organs. The immature Odonates (Insecta) have their rectum modified into a *branchial basket.* Its wall is contractile and richly supplied with the branches of tracheae. This kind of respiration is often referred as *anal respiration.*

Aerial respiration

Trachea. This is the most important organ for aerial respiration. This chitin-lined tube is seen in almost all land arthropods and is best developed in insects. Two types of tracheae are seen: (*i*) *ventillation trachea*—oval in section and collapses after the exhalation of air and (*ii*) *diffused trachea*—rigid and does not collapse after the exhalation. The tracheae originate as the invagination of body wall. (*a*) **Structures of tracheae and associated parts**—Each trachea is a tube with walls made up of polygonal cells and is internally lined by spiral ridges, the *taenidea.* The tracheae open externally by small openings called *spiracles.* Each spiracle is placed within a chamber and on a plate called *penetrene.* Each spiracle has two lids for opening and closing. Within the chamber foreign particles are eliminated by a filtering apparatus, containing either special bundles of setae or a kind of sieve-like membrane. Some parts of tracheae are dilated to form *air-sacs* which work as reservoirs. The finer branches of tracheae are called *tracheoles* which are without inner taenidial ridges. A tracheole may be one micrometre in diameter and reaches every cell of the body. The end of a finer tracheole is immersed in a fluid through which gaseous exchange takes place. (*b*) **Classification of tracheae**—In adult insects, the tracheal system is of one kind. *Two* thoracic and *eight* abdominal spiracles are usually present in all adult insects. In certain forms some spiracles may be secondarily absent but they appear at least in some stages of development. For example, the queen of termite has only *six* abdominal spiracles instead of *eight.* The metathoracic spiracle is absent in orders like Lepidoptera, Hymenoptera, Colleoptera and a few others. But during development, spiracles appear in varied ways in different insects. Thus from the point of view of embryology the tracheal system is classified on the basis of the number of functional spiracles. This classification does not denote any special kind of tracheal system in an adult. According to the classification, the tracheal system in larvae may be: (*i*) **Polypneustic.** When *eight* or more pairs of functional spiracles are present. It may again be subdivided into *holopneustic* (2 thoracic and 8 abdominal spiracles), *peripneustic* (1 thoracic and 8 abdominal) and *hemipneustic* (1 thoracic and 7 abdominal). (*ii*) **Oligopneustic.** Here, either *one* or *two* pairs of spiracles are functional. It includes divisions like *amphipneustic* (1 pair of thoracic and 1 pair of post abdominal), *metapneustic* (1 pair of post abdominal) and *propneustic* (1 pair of thoracic). (*iii*) **Apneustic.** No spiracle is present in functional state. (*c*) **Mechanism of tracheal respiration.** The movement of trachea is facilitated by the alternate contraction and relaxation of the body sclerites. In bed bugs, rigid and convex sternum does not take part in the respiratory movement, which is done only by the elastic tergum. In cockroaches the tergum and sternum of the segments are separated by intersegmental membrane which bulges out during respiration. (*d*) **Modifications of the tracheae.** In Onychophora, the irregular tracheal pits open to the unbranched tracheal system. In most Collembola, the tracheae are absent and the respiration is largely cutaneous. In *Machiles*, segmental tracheae originate from spiracles but do not have trunks. In the larva of *Musca*, dorsal longitudinal trunk is provided with one pair of anterior and one pair of posterior apertures. In the larvae of mosquito, a single spiracle is connected to the dorsal trunk. In the Myriapods, stigmata open within air chamber from where large numbers of tracheae are given off. The

other peculiar features of this group are that in Diplopoda the tracheae are branched and in Symphyla only two tracheae are present on the head. The only land living Crustacea, wood lice, have *pseudotracheae*. These are formed by numerous minute tube-like structures which traverse the pleopods.

Other devices of aerial respiration

(1) *Lungs:* In the Crustacea, *Birgus*, the upper part of the gill chamber is separated from the rest and forms a closed chamber within which vascular tufts project.

(2) *Book lungs:* The book lungs are best seen in Scorpionids. These are blind sacs which originate from the evaginations of opisthosoma. These are regarded as the modified abdominal appendages. Within the sac the inner lining is raised into numerous delicate folds, like the leaves of a book. These folds are richly vascularised and thus respiration in Scorpionids is circulation dependent. Each book lung communicates to the exterior by a stigma.

(3) *Anal respiration:* Many crustaceans perform rhythmical contractions of intestine—taking in and expelling out water. Such anal respiration is common in lower crustaceans and is especially noticeable in Cyclops.

(4) *Miscellaneous devices:* A combination of book lung with trachea is seen in spiders. Some aquatic members of Colleoptera and Hemiptera, while diving inside the water, carry air with them for respiration. In mosquito larvae, a long siphon draws air from the surface of the water.

EXCRETORY SYSTEM

This system is concerned with the removal of metabolic wastes which include various nitrogenous substances and water. Various organs are found in arthropoda which are excretory in function (Fig. 16.124). These organs are—*nephridia, coxal gland, green gland, shell gland* and *Malpighian tubules*. Excepting the last, the other organs are modified coelomoducts. In addition to these, there are a few more organs which are also excretory. (*i*) **Nephridia.** These are present in the Peripatus and are situated on the lateral side of the segmented body cavity. Number of these paired organs correspond to the number of the segments of the trunk. Each nephridium consists of a terminal vesicle which opens to the exterior through one end and remains connected to a coiled loop with the other. This loop is known as nephridial canal and it opens inside the body cavity. Its internal lining is ciliated. (*ii*) **Coxal glands.** These glands are present only in Arachnida and their structures and positions vary (see Table 6—Arthropoda). Each coxal gland consists of convoluted tubules, called *labyrinth* and a sac called *labyrinth sac*. It opens externally by a short tube. (*iii*) **Green gland.** It is also known as the antennary gland. It is found in Malacostraca (excepting Isopods) and larval forms of all Crustaceans, specially in Entomostracan larvae. It is present in the proximal segment of the second antenna or adjoining regions of the head. Each gland has three parts—*end sac, labyrinth* and *bladder*. The labyrinth is the proper excretory gland.

Table 6—Arthropoda

Structure and position of coxal glands in arachnids

EXAMPLES	POSITION	LABYRINTH SAC	LABYRINTH	EXIT
Solifugae	2nd or 3rd segment.	Short.	Very extensively coiled.	On pedipalpi.
Amblypygi and Uropygi	3rd segment.		Much coiled between 5th and 6th segments.	1st leg.
Scorpionidae	5th segment.		Do.	3rd leg.
Araneida	3rd & 6th segments.			1st & 3rd legs.
Palpigradi	2nd segment.	Very long, extends up to 8th segment.	Short and sac-like.	On pedipalpi.

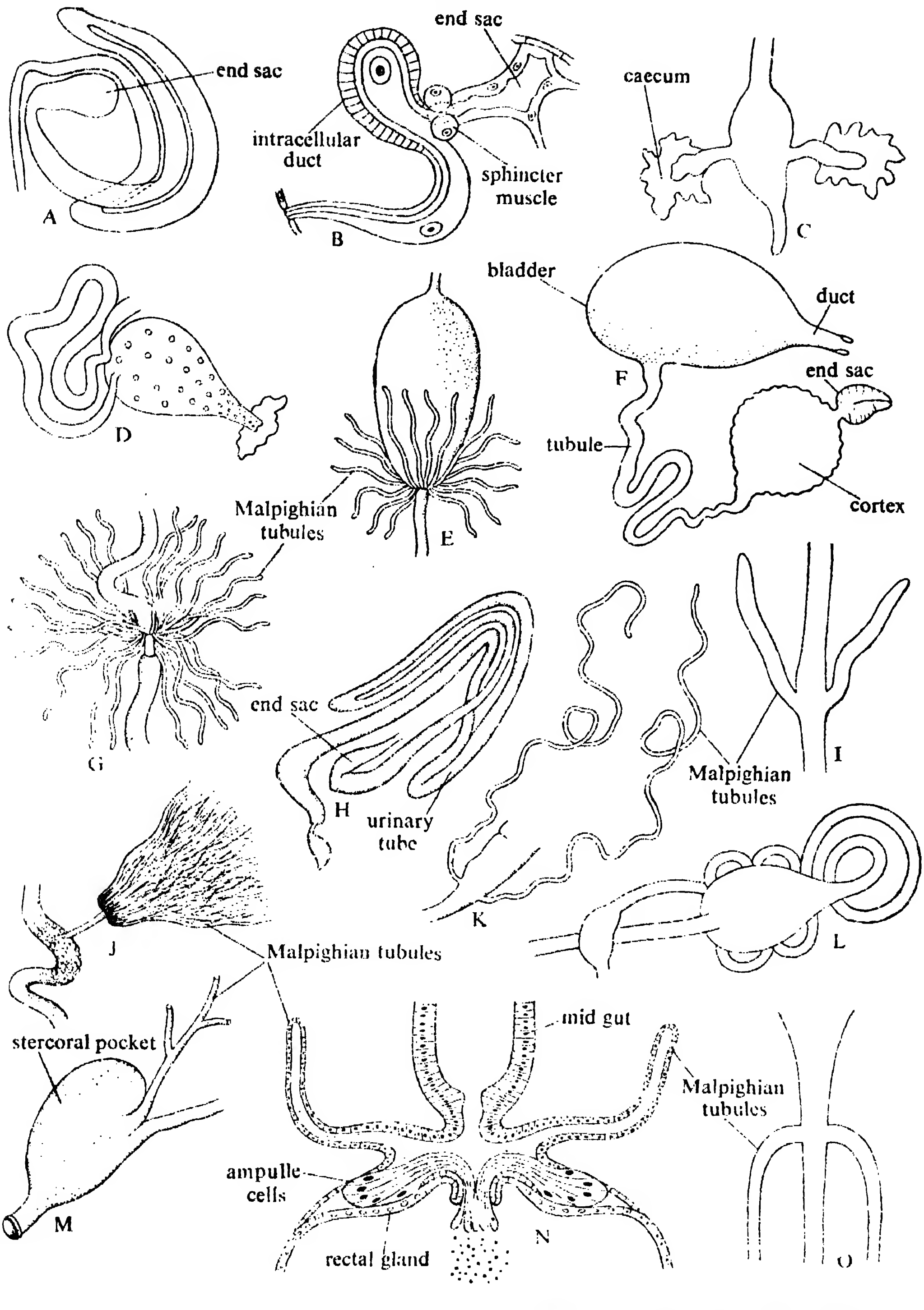


Fig. 16.124. Excretory structures of a few arthropods. A. Maxillary gland of *Estheria* (Crustacea). B. Antennal gland of *Estheria* larva (Crustacea). C. Intestinal caeca of *Squilla* (Crustacea). D. Nephridium of Peripatus (Onychophore). E. Malpighian tubules of *Xyphidria* (Insect). F. Green gland of *Astacus* (Crustacea). G. Malpighian tubules of *Stilopyga* (Insect). H. Shell gland of *Triops* (Crustacea). I. Malpighian tubules of scorpion (Arachnida). J. Malpighian tubules of Mole cricket (Insect). K. Malpighian tubules of *Lithobius* (Myriapod). L. Coxal gland of scorpion (Arachnid). M. Malpighian tubules and stercoral pocket of spider (Arachnida). N. L. S. of insect gut to show the junction of Malpighian tubules and gut. O. Malpighian tubules in Amphipoda (Crustacea).

(*iv*) **Shell glands.** These glands are also known as *maxillary glands* and are present in the coxopodites of second maxillae in Branchiopoda, Ostracoda, Copepoda, Cirripedia and larval forms of all Crustaceans. (*v*) **Malpighian tubules.** These are long filamentous bodies with or without lumen and are made up of ciliated or cubical epithelium. These tubules usually originate from the region of the gut which denotes the beginning of hind gut. Among the Crustaceans, the Amphipods possess one pair of tubules which originate as diverticula of the alimentary canal. In Insecta these are ectodermal in origin and the number vary from 2 to 150. Malpighian tubules are absent in Collembola and Aphids. Two to four pairs of tubules are found in Myriapods and Arachnids and in the later the tubules are endodermal in origin. (*vi*) **Hepatopancreas.** In *Limulus*, absorptive cells are present in the hepatopancreas. These cells shed large amount of calcium phosphate as excretory product into the intestine through which it is eliminated along with faeces. (*vii*) **Fat body.** In Insecta, Myriapoda and Onychophora, the fat bodies are made up of polygonal cells. The cells, as they grow old, become filled up with minute urate crystals. (*viii*) **Exoskeleton.** In Crustaceans and Insects, the cells of the hypodermis secrete nitrogenous substances which remain deposited within the exoskeleton. These are eliminated at the time of ecdysis. (*ix*) **Intestinal caeca.** In *Squilla*, the rectum bears a pair of intestinal caeca having a comb-like internal wall. These are believed to be excretory in function. (*x*) **Mid gut epithelium.** In Nauplius larvae of Crustacea, the cells surrounding the mid gut carry out excretory function. (*xi*) **Pericardial cells.** In Insects some cells around the heart and the pericardial membrane are excretory in function. (*xii*) **Nephrocytes.** These are migratory cells, present in groups within the haemocoel of insects. These are regarded as modified fat body cells. (*xiii*) **Oenocytes.** In Insects and Myriapods, certain cells are found in groups around the abdominal spiracles. These cells originate from surface epithelium and are believed to be both excretory and circulatory in functions.

The excretory system is well-developed in land-living arthropods, which are concerned with the problem of water loss. In them the excretory organs work in such a way that very little water is lost from the body.

CIRCULATORY SYSTEM

The circulatory system is primarily concerned with the distribution of metabolic substances and respiratory gases. In all Arthropods, excepting Insects, the circulatory system performs this dual role. In Insects, the circulatory system is free from the burden of carrying respiratory gases. This system includes, *blood*, *blood vessels* and a pumping organ, the *heart*. The circulatory system in Arthropods shows a trend of transition from primitiveness to specialisation.

Blood. In Crustaceans, the blood contains a fluid part, plasma and a few colourless amoeboid cells. A copper-containing pigment *haemocyanin* is present in the plasma of Decapods to render a blue colour to the blood. In Crustaceans like *Triops*, and *Cypris*, the colouring pigment is *haemoglobin* which makes the colour of their blood red. Among the Myriapods, the Chilopods have colourless blood and in *Lithobius* the blood is violet. In Insects, the blood is usually colourless. In leaf eating Insects, the blood is green and in some other forms it may be brownish or yellowish. In Chironomous larvae, the blood is red. In Arachnids, the presence of haemoglobin in blood plasma has given red colour to the blood.

Blood vessels. In general, the blood flows through coelomic spaces called haemocoel, but in addition there are vessels with definite walls in Crustacea and others. Such vessels are called the *arteries*. In Arachnida, there are both arteries and veins with definite walls.

Heart. Certain Arthropods, like Cirripeds, Ostracods, Copepods and Pauropods do not possess any heart. When present, the heart is always dorsal. The primitive heart is tubular and extends along the entire length of the body. In other forms various types of shortening, thickening and compartmentalisation are noted. Among the Crustaceans, the primitive type of elongated tubular heart is noted in Branchiopoda and Anostraca. In each segment it

communicates through a pair of ostia. More or less similar condition is seen in Leptostraca, Stomatopoda, Isopoda and Amphipoda. The heart is short and sac-like in Cladocera and Decapoda and it has only a few pairs of ostia. In Myriapoda, the elongated tubular heart is internally divided into several chambers. In *Scolopendra*, it is enclosed within a cardiac diaphragm. The wall of the diaphragm is attached with the body wall and special sets of muscle called *allary muscle* remain associated with it. In Insecta, the tubular heart is generally confined to the abdomen but in many instances it extends up to the thorax. The inner chambers of the heart are interconnected by openings which are guarded by valves. The heart opens into the pericardial cavity by several ostia and the wall of the heart remains attached with the body wall by allary muscles. In Arachnida, the length of heart and the number of chambers vary. For example, the heart of scorpion has seven chambers and the spider possesses only three. In Xiphossurids, the heart has eight chambers.

NERVOUS SYSTEM

The nervous system includes—(*a*) *Central nervous system*, (*b*) *Peripheral nervous system* and (*c*) *Sense organs*. Some higher Crustaceans and Insects, possess a *sympathetic nerve cord* which begins from the central nervous system and extends along the wall of the alimentary canal. In spite of tremendous diversity, the nervous system in Arthropoda is built up on a basic plan which includes a pair of ganglia per metamere. These ganglia are interconnected by nerve cords and peripheral nerves are given out to the particular segment. This basic plan has been modified in various Arthropods, according to the modification of their body and in many instances fusion of the ganglia have taken place (Fig. 16.125).

Central and Peripheral nervous systems. Within CRUSTACEA, the Branchiopods exhibit primitive type of nervous system which resembles that of Annelids. Here brain is formed by the fusion of two pairs of ganglia representing the segments bearing eyes and antennules respectively. These two pairs are known as *protocerebrum* and *deuterocerebrum*. From *brain* arises paired *circum oesophageal connectives* which come in contact with paired ventral nerve cords. The nerve cords run posteriorly and carry a pair of ganglia in each segment. The anteriormost pair of ganglia is known as *suboesophageal ganglia*. But in other Crustaceans the ganglia of the antennal segment also fuse with the brain and form its third lobe called *tritocerebrum*. In some Crustacea, paired ganglia of each segment are fused, in others the ventral nerve cord is reduced. In the case of prawn, the ganglia of the thoracic segments are fused to form a single ganglionic mass and in crab (*Carcinus*) entire ventral nerve cord is fused. Its segmental ganglia are united to form a large ventral ganglionated mass. Similar reduction is also seen in Cirripeds. Such reduction in Cirripeds is possibly due to their parasitic existence.

In MYRIAPODS, the ventral nerve cord exhibits its double nature and this is distinct specially among the Chilopods. Three ganglia on the ventral nerve cord corresponding to the first three trunk segments unite to form a sub- or infra-oesophageal mass.

In INSECTS, the usual pattern is that, after suboesophageal mass, each segment of the thorax and abdomen has a pair of ganglia on the ventral nerve cord. But in *Nepa* and *Acanthia*, the first thoracic ganglia are fused with the suboesophageal. In *Gyrinus*, all the abdominal ganglia are fused and in *Lachnosterna* the abdominal ganglia are fused with the ganglia of meso- and metathorax. The best examples of condensation are seen in Diptera. In *Sarcophaga*, all the thoracic and abdominal ganglia are fused together. Such condensation includes even the suboesophageal ganglia in the parasitic Diptera, *Pupipara*.

Among the CHELICERATES the nervous system shows different grades of fusion. In Xiphosurids, suboesophageal ganglia remain fused with the ganglia belonging to the segments second to eighth. The ventral nerve cords bear four ganglia and the last ganglia are formed by the fusion of ganglia belonging to the last three segments. In Scorpionids, the thoracic ganglia are fused with the suboesophageal ganglionic mass but most of the abdominal ganglia are distinct. In Araneida, all the ganglia are fused into a mass, which is pierced by the oesophagus.

Sense organs. The possession of well-developed sense organs has played important role in the success of arthropods.

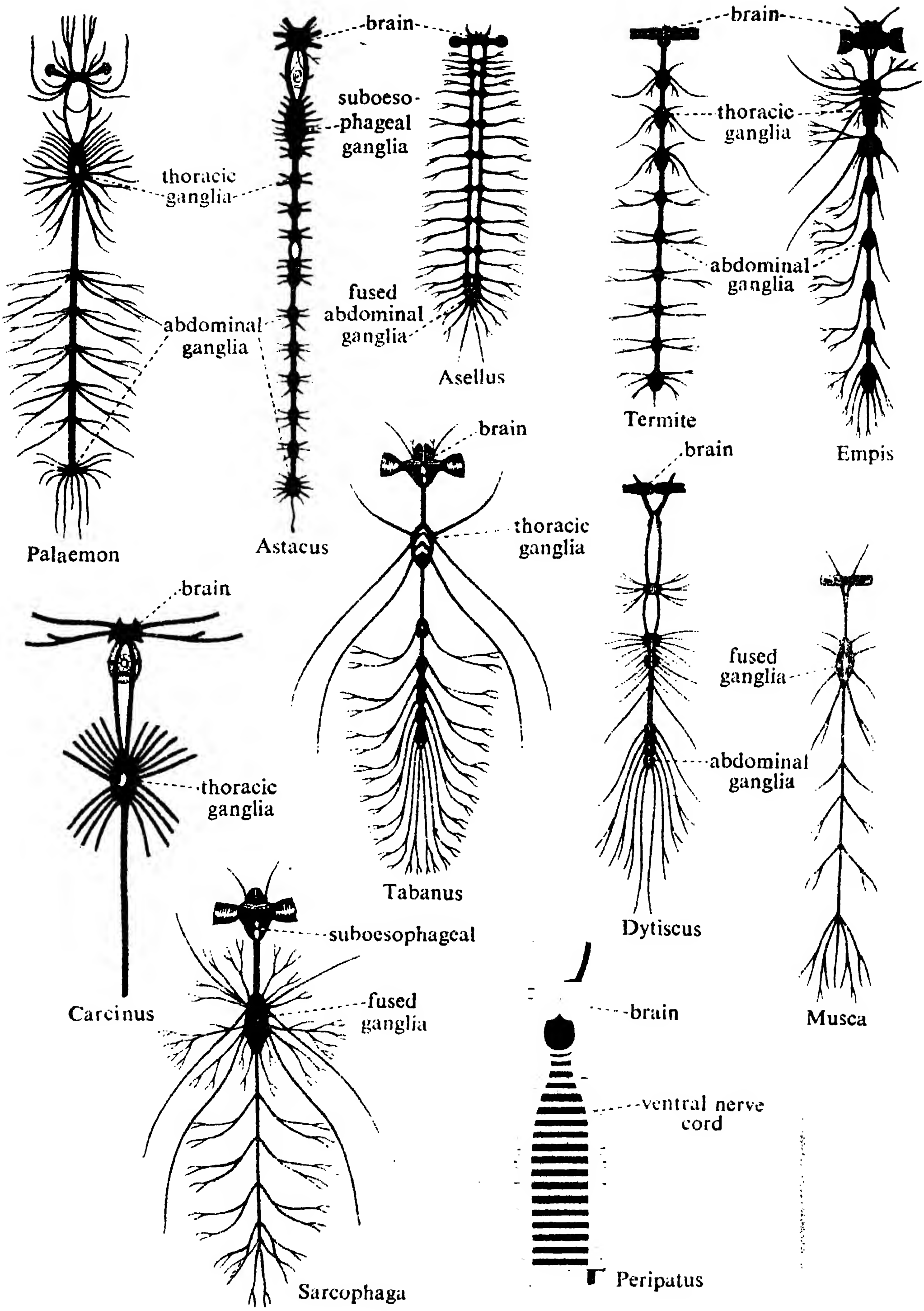


Fig. 16.125. Nervous system of a few arthropods. Note that in peripatus, ventral nerve cords are completely separated. Among the Crustaceans in *Asellus*, the ventral nerve cords and their segmented ganglia are separate in the major part of the body, but in *Astacus* and *Palaemon* two nerve cords and the segmented ganglia are fused. In *Palaemon* thoracic ganglia are fused to form a compact mass. In *Carcinus*, such a mass is formed by the fusion of both thoracic and abdominal ganglia. Among the Insects only the termites exhibit least shortened nerve cord but others exhibit different trend of shortening. The climax is seen in *Musca* and *Sarcophaga* where both the thoracic and abdominal ganglia are fused to form a ganglionic mass.

Starting from setae and bristles there are extremely specialised sense organs like compound eyes (Fig. 16.126) to act as ports of entry of different stimuli.

CRUSTACEAN SENSE ORGANS. The important sense organs are *eyes*, *statocysts* and *olfactory setae*. In addition, there are various *sensory hairs* and *bristles*. (*i*) **Eye.** The eye may be single or paired. In Ostracoda, single median eye is placed on the anterior end. Similar median eyes on the dorsal side are seen in free-swimming Copepods. The eyes are absent in parasitic Copepods and degenerated in Cirripedia and Rhizocephala. The paired eyes are generally mounted on stalks but may be sessile as organs or statocysts are present in the antennule. In Mysidacea, the balancing organs are present in the uropods. In the land-living Crustaceans (including true crabs and hermit crabs), the statocysts are also responsible for receiving vibrations. (*iii*) **Olfactory setae.** These setae work for receiving smell and are distributed over the antennae.

MYRIAPOD SENSE ORGANS. The sense organs are generally seen as *sensory hairs*, *eyes* and other *specialised organs*. (*a*) **Sensory hairs.** These hairs either remain scattered all over the body or are found, in specialised groups, in certain regions of the body. In Pauropoda, five pairs of tactile hairs are

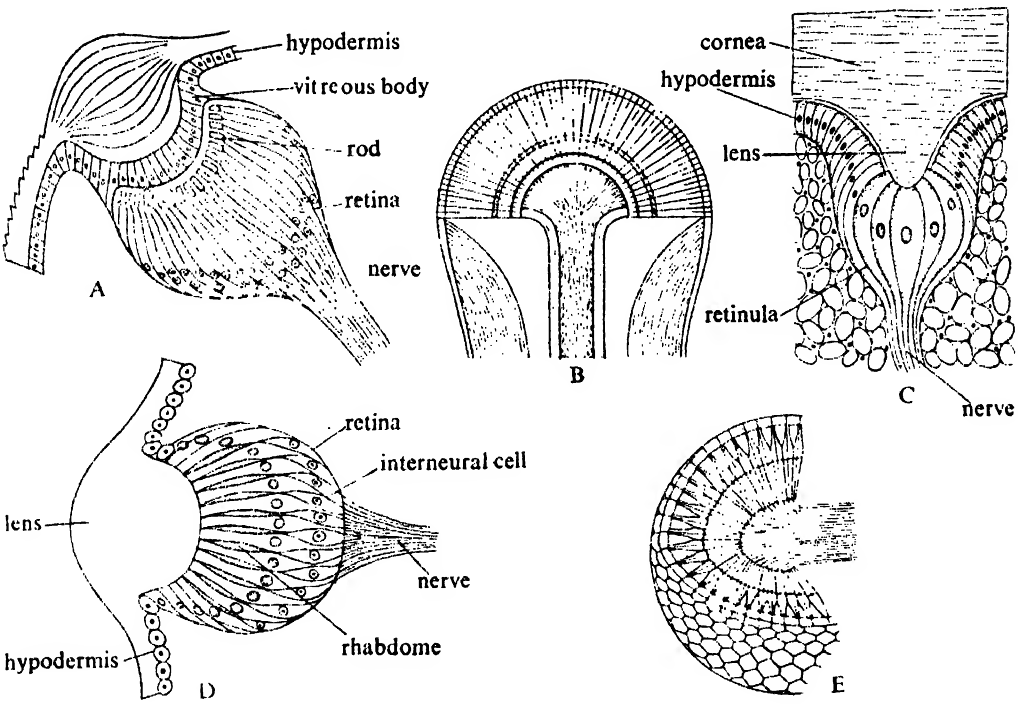


Fig. 16.126. Sectional view of eye in different arthropods. A. Anterior median eye of spider. B. Compound eye of *Palaemon*. C. An ommatidium of the lateral eye of *Limulus*. D. Lateral eye of scorpion. E. A typical insect eye.

in Cumacia, Tanaidacea and Amphipoda. In many Branchiopods, the eyes remain within a fold of epidermis. The eye stalk is usually jointed but in many Branchiopods the stalk is unjointed. In *Cladocera*, the paired eyes are fused. The unpaired median eye is known as *nauplius eye* and is simple in design. But the compound eye contains numerous visual elements called ommatidia (*sing*. ommatidium). The structure of an ommatidium is same as in prawn. (*ii*) **Statocyst.** The balancing

arranged along the sides of the tergal plates of second to sixth segments. In between eyes and antennae of Diplopods, a small pit contains projectile hairs. Its *gnathochilarium* (formed by the fusion of antennae, maxillae and mandibles) carries tufts of sensory hairs. In Diplopoda, sensory hairs and sensory spines are seen in different parts of the body. (*b*) **Eye.** Eyes are absent in Symphyla (excepting a few cases, where only one pair is present). An eye-like surface is visible in Pauropoda,

but true eye is not present. Several simple eyes are clumped together in Diplopoda. In others the eyes, when present, are usually simple. In *Scutigera*, a kind of pseudocompound eye is present. (*c*) **Specialised sensory organs**—(*i*) *Globulus*. It is present on the ventral branch of Pauropoda. (*ii*) *Organs of Tomosvary*. In Diplopoda, the head bears a pair of small projections. It is dressed externally with fine hairs and inside the projection, the hypodermal cells are provided with nerves to receive sounds. (*iii*) *Maxillary organs*. The inner side of the base of the first maxilla possesses a pit with profuse lining of setae. (*iv*) *Parapodia*. In Symphyla, last ten pairs of legs have wart-like stumpy processes called parapodia. Each parapodium contains a sac having sensory function.

INSECT SENSE ORGANS Following sense organs are usually seen in insects. (*i*) *Eyes*, (*ii*) *Olfactory organs*, (*iii*) *Organs for touch and taste*, (*iv*) *Auditory organs* and (*v*) *Chordotonal organs*.

(*i*) **Eyes.** The eyes of insects may be compound or simple. The compound eyes are without stalks and are spread on the marginal part of the head. Many subterranean insects are completely blind. The number of simple eyes vary widely. These are absent in Dermaptera and in some Hemiptera. When present, the simple eyes are grouped along the sides of the head.

(*ii*) **Organs of smell.** The tip of each antenna bears hairs which are embedded in pits and act as the sense organ for smell.

(*iii*) **Organs for touch and taste.** Numerous hairs with nerve connections protrude throughout the surface of the body for getting stimuli in the form of touch. Specially the hairs around palp serve dual functions of touch and taste. The hairs present around mouth parts are probably for the function of taste.

(*iv*) **Organs for receiving sound.** Some insects (male Culicids) have specialised hairs over the surface of the antennae for detecting sound. A special organ called tympanum is seen in several insects (in the anterior segments of Acridiidae, in anterior legs of Locustidae). This organ has a fluid-filled vesicle inside to act as membranous labyrinth. The organ has connections with nerves supplied from third thoracic ganglion.

(*v*) **Chordotonal organs.** These specialised sense organs are located in different parts of the body specially in legs and abdomen. Each organ consists of a pack of sensory cells and accessory structures called *scolopales*. These may remain tightly stretched and attached on both the ends of hypodermis or only one end remains attached. They perform various functions which include regulation of leg movement (*Proprioceptive organ*) and also reception of sound waves.

CHELICERATE SENSE ORGANS. Following sense organs are seen in different Chelicerates—*eyes*, *sensory setae*, *trichobothria*, *slit sense organs*, *frontal organs* and *pectines*.

(*i*) **Eye.** In Eurypteridae, the cephalothorax bears a pair of large eyes and a pair of small eyes. In *Limulus*, similar disposition of eyes is marked but the *median eyes* are compound in nature. Scorpions have a pair of large centrally placed eyes on the cephalothorax and several pairs of small eyes along the anterolateral margin. The median eyes are intermediate between simple and compound eyes. Each eye has a single cuticular lens like that of a simple eye but retinal cells are disposed like compound eyes. In the Pedipalpidia, two median eyes are large and six small eyes are placed along the margin. The arrangements of 6–8 simple eyes in spiders vary widely and serve as the criteria in classification. The Solifugae and Phalangida possess a pair of eyes on the head and the Acarids are without eyes.

(*ii*) **Sensory setae.** All over the cuticle, specially on the masticating processes of the thoracic limbs, numerous hair-like structures are present. These setae are provided with the branches of nerves and are sensory in function. (*iii*) **Trichobothria.** These flask-shaped sense organs with a mobile seta are arranged on each chela in different planes. These are responsible for determining air current. (*iv*) **Slit sense organs.** These slit-like sense organs are distributed all over the body, specially over the appendages. Each minute slit is covered by a membrane and leads to a crevice. Inner end of the crevice leads to a membrane-lined tube which is internally supplied by numerous nerve fibres. These sense organs co-ordinate joint movement and work as vibration receptors. (*v*) **Pectines.** These specialised sense organs are found in Scorpion. Males with the help of

these sense organs detect suitable surface for depositing spermatophores and the females use these for collecting spermatophores. (*vi*) **Frontal organs.** These specialised sense organs in the form of hairy areas are seen in Xiphosurids. These organs act as photoreceptors in larva but their function is not known in adult.

REPRODUCTIVE SYSTEM

The secret of success of the Arthropods as a phylum lies in its prolific rate of multiplication. This is done by efficient reproductive organs and effective reproductive behaviour. Majority of the arthropods are unisexual. A good number of hermaphrodites are seen in all the classes excepting Arachnida. Each reproductive duct is a modified coelomoduct and reproductive gland or gonad opens into it. The position of the reproductive organ varies as also the sites of reproductive openings. Majority of the arthropods are oviparous and it is curious enough that in most of them there are certain devices for internal fertilization. Some forms of viviparity are also seen, but only in Onychophores, true viviparous condition is found.

Modification of different classes

CRUSTACEA. Free-living Crustaceans are generally *unisexual*. But in Cirripeds, parasitic Isopods and in a few other species, *hermaphroditism* is encountered. Such hermaphrodites are called *protandrous* because in them male reproductive organs appear first and then the female organs. Though males often possess well-developed appendages, yet generally they are smaller in size than females. In some forms of parasitic Crustaceans, males are extremely minute and cling to the body of the females. Such males are called *complemental males*. In many Crustaceans, males may have modified appendages to act as *clasping* or *intromittent organs*. The intromittent organs (structures for transferring sperms to the female body) may also be formed by the modification of the protrusible terminal part of the vasa deferentia.

The reproductive organs in both the sexes are hollow and are usually united either completely or incompletely above the alimentary canal.

In all the Crustaceans (excepting Cirripedia, Malacostraca and some Cladocera) both the sexes have reproductive openings in the same segment. The genital apertures in most Crustaceans are placed near the posterior end of the thorax. Both in Cirripeds and in some Cladocera the male apertures are terminal and the female opening in Cirripeds is at the first thoracic segment. The sperm cells may be of varied forms—*Polyphemus* (Cladocera)—amoeboid; Copepods—sausage-shaped; Decapods, Euphausids and Stomatopods—spherical and with rigid radial processes; Isopods and Amphipods—thread-like; Ostracods—sperms are many times larger than the body of the individual.

Round eggs may have varied concentrations of yolk. Usually the female carries the eggs after fertilization through some devices but in some cases the eggs may remain uncared.

MYRIAPODA. The reproductive organs are unpaired. In Centipeds, genital aperture is placed near the posteriormost end of the body. But in Millipeds the apertures are not far away from the head. Some Myriapods protect their eggs up to certain period after laying.

INSECTA. All insects are unisexual excepting *Icerya purchasi*, which is hermaphrodite and practises self-fertilization.

The *testes* are generally small, paired and sometimes follicular. Number of follicles vary from one in Diptera to many in Orthoptera. A duct called the *vas efferens*, connects the follicles. Thread-like sperms are usually packed as *spermatophores*.

The *ovary* is made up of *ovarioles*. The number of ovarioles is usually six to eight, but in female Termite it is 1500, in queen bee several hundreds, but in Tsetse fly only one.

Usually two oviducts unite to form a single duct but in Ephemidae and *Lepisma*, two oviducts open separately.

The genital openings are placed in the ninth and tenth abdominal segments and have in many cases copulatory structures.

The egg is usually ladden with yolk, excepting parasitic Hymenoptera and has a covering of vitelline membrane and rigid chorion. Several openings are present on the chorion for sperm entrance. Copulation usually takes place long before fertilization and sperms are kept within the spermathecae of the female body. Fertilization

occurs at the time of egg laying and thus is under voluntary control of the female. For the laying of eggs many insects are provided with special structures which are generally used for digging.

The number of eggs laid vary in different insects. Termites, ants and bees lay a few thousands of eggs at a time. But in Tsetse fly, one egg is released every 9–10 days. Here fertilization and major part of the development take place within a special chamber called '*uterus*'. Many insects lay their eggs directly within the body of some other insects.

Chelicerate. Excepting spiders and certain mites, no sexual dimorphism is noted in Arachnida. In Scorpion both the processes, fertilization and development are internal and some form of courtship is noted. The eggs are small and are without yolk. Similar viviparous developments are also noted in Pedipalpi and mites.

In *Limulus* fertilization is external and occurs on land.

In Araneida, in both the sexes the openings are present on the middle line of the epigastric furrow. A special structure called *epigynum* is associated with the genital opening of the female. The epigynum is simplest in *Pirata* and modified for egg laying in *Aranaea angulate*. Male Araneids have pedipalps modified to act as intromittent organs. In females, a single oviduct connects both the ovaries. In both the sexes of Chelicerates, single genital opening serves as the outlet, except in *Limulus* where it is paired.

LIFE HISTORY

Though sexual reproduction is a prerequisite for the initiation of development in Arthropods yet instances of parthenogenesis are plenty. Among the Crustaceans, Branchiopoda and Ostracoda usually develop parthenogenetically. In Triops, sexual reproduction is restricted only at a particular time of the year and during the rest of the time development takes place parthenogenetically. Among the Insects parthenogenesis is common in aphids and certain members of Hymenoptera. The common black wasp usually develops parthenogenetically, because male varieties are extremely rare in nature. The larvae of a Dipteran insect, *Miaster* can produce eggs which develop parthenogenetically.

Usually one embryo develops from one egg but in parasitic Hymenoptera belonging to the family Chlacididae, one egg splits into several hundred bits, each of which forms a complete embryo. This phenomenon of *polyembryony* is extremely interesting from the point of view of embryology, because it results in the production of identical twins (here, of course, identical hundreds) having similar genetic make-up.

A general survey of life history in the different groups of Arthropods reveals the existence of three categories of development:

(1) *Direct development*. From the egg hatches out an individual, which resembles the adult in all respects except the size.

(2) *Incomplete metamorphosis*. The young resembles the adult but many adult structures are lacking. Such structures appear later in course of further development.

(3) *Complete metamorphosis*. The young which comes out of the egg has no semblance with the adult and it lives an independent and completely different sort of life. From this condition it passes usually into a stationary phase and from it emerges the adult. The details of these three categories of development will be discussed separately in the different classes of Arthropoda.

Crustacea. The metamorphosis is usually complete in Crustacea. The young one which comes out of the egg is called a *larva*. It usually passes through an independent life and subsequently transforms into an adult. In certain Crustaceans, e.g. *Palaemon*, *Argulus*, larva does not come out of the egg. Thus transformation occurs internally and a young resembling the adult is hatched out. Within the class Crustacea, variety of larval forms (Figs. 16.127 and 16.128) are seen and in many groups one type of larva transforms into another type and finally becomes the adult.

Different types of Crustacean larvae

Nauplius larva. The free-swimming larva is oval and the body is divisible into three regions—*head*, *trunk* and *anal region*. A median frontal eye is present in the head region. Three pairs of appendages are present, of which the first pair are unjointed

and present in the head region. It develops into the antennule of the adult. The remaining two pairs are biramous and are present in the trunk region. The

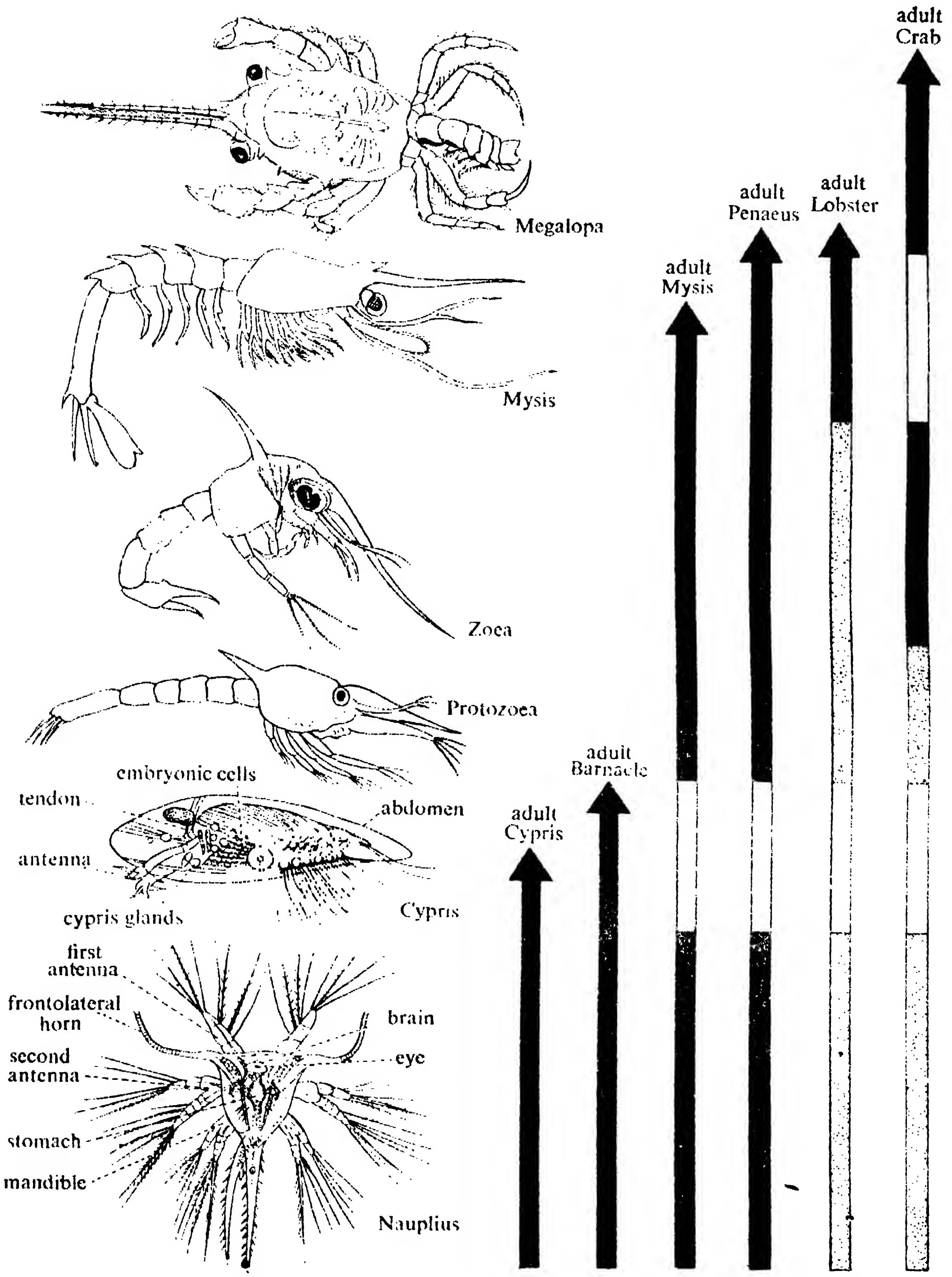


Fig. 16.127. Larval stages of Crustacea. Arrows illustrate the recapitulation during the development of six Crustaceans. Arrow indicates larval stage (shown in left) through which the individual passes during development. The white region in arrow denotes missing stage, shaded area represents stage inside the egg and black area indicates free-swimming stage.

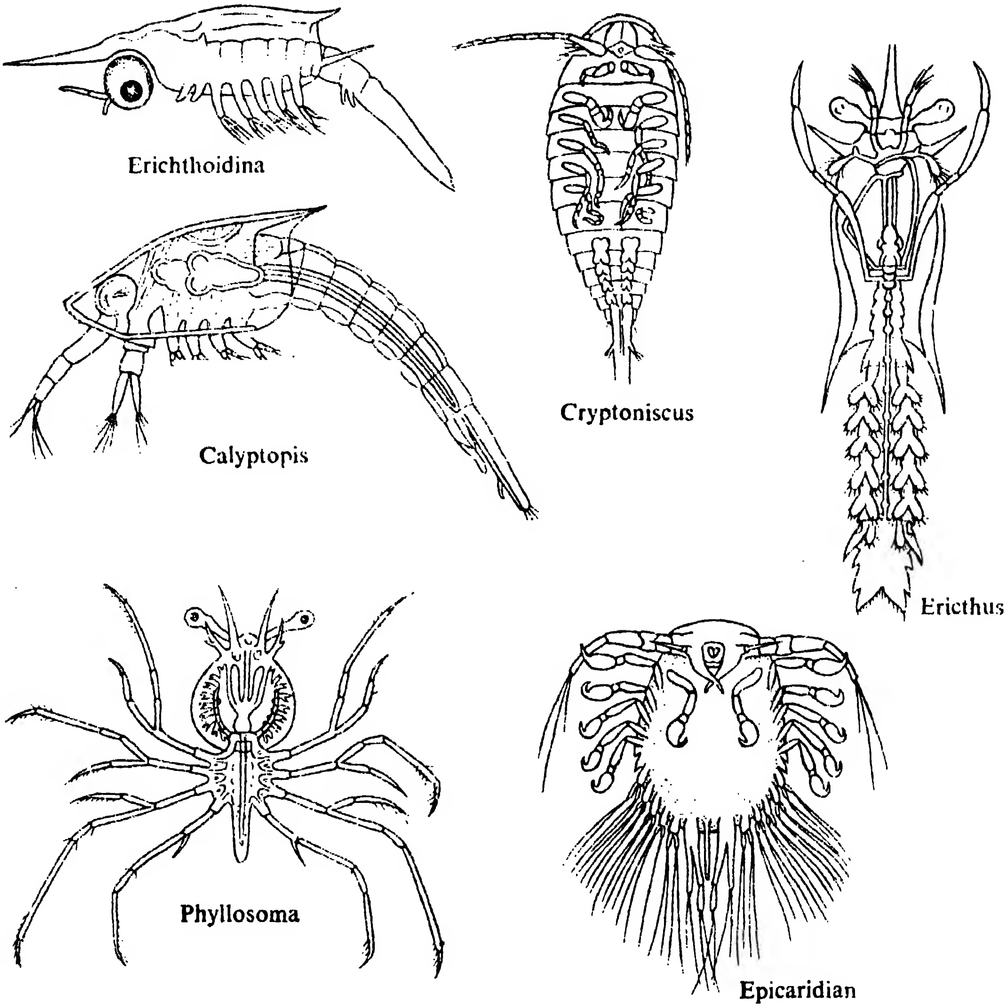


Fig. 16.128. A few larval stages of Crustacea.

first pair of trunk appendages which act as locomotor organs in larvae, transform into antennae and the second pair become the mandibles of the adult. Mouth is present in between the two trunk appendages and is enclosed by a prominent labrum. Alimentary canal is straight and terminates at the posteriormost end of the anal segment through the anus.

In all Crustaceans the nauplius is the first larval stage of development. But its appearance varies in different forms. In Cladocera, nauplius stage appears inside the egg. In Ostracoda nauplius, a pair of bivalved shells and uniramous appendages are present. In the Cirripedia, a number of spines are present in the nauplius. Alimentary canal is absent in Sacculina nauplius. In Isopoda, nauplius is maggot-like.

Metanauplius larva. The oval body is divided into cephalothorax and rudiments of abdomen. Presence of a fourth pair of appendages (first maxilla of the adult) in addition to the original three pairs of the Nauplius is observed. Two truncated processes at the posterior end are present. This stage is seen in *Triops* (Branchiopoda) and *Penaeus* (Malacostraca).

Cypris larva. Body is enclosed in a bivalve shell. A median and two compound eyes are present. Anterior antennae are four-jointed and each bears a characteristic disc. Posterior antennae are absent. Six pairs of biramous thoracic appendages are present. Short abdomen ends in a caudal fork. It occurs in *Sacculina* and barnacles (Cirripedia).

Protozoea larva. First antenna is four-jointed. Second antenna is with three-jointed endopodite and four-jointed exopodite. Mandibles are palpless, toothed and masticatory in function. Two anterior pairs of maxillipeds are biramous. Abdomen is incompletely segmented. Impressions of paired eyes are visible. It is found in *Penaeus*.

Zoea larva. Body is divided into distinct cephalothorax and segmented abdomen. Compound eyes are prominent and stalked. Head bears a dorsal, a frontal and two lateral spines. Limbless abdomen is with six segments including a telson. Seven pairs of cephalothoracic appendages are present. This stage appears in *Penaeus* and crabs (Malacostraca). In *Euphausia* corresponding stage is *Calyptopis*.

Mysis larva. Body is divisible into cephalothorax and six-segmented abdomen with a telson. Biramous thoracic appendages are present. Presence of a pair of stalked compound eyes is encountered. It appears during development in *Penaeus*.

Metazoea larva. Body is divisible into cephalothorax and abdomen. The abdomen has a pair of telsons. Thoracic limbs are well-developed. Abdomen is with biramous pleopods. This stage is distinct in the life history of *Corystes* (Malacostraca).

Megalopa larva. Cephalothorax is well-developed. Large stalked eyes are distinctly visible. Thorax is with five pairs of walking legs. Functional swimmerets are present on the abdomen. It is commonly seen in the development of crabs (Malacostraca).

Kentrogen larva. Body is sac-like and elongated. Undifferentiated mass of cells is present inside the body. It is seen in the parasitic form like *Sacculina* (Cirripedia).

Epicaridian larva. Two pairs of antennae are prominent. A pair of frontal processes and a pair of mandibles are present. Presence of six pairs of limbs in the thorax. Abdomen includes six pairs of biramous pleopods. This larva transforms into *Cryptoniscas* larva. It occurs in parasitic Isopods.

Erichthus larva. Body is divisible into cephalothorax and abdomen. Anterior thoracic limbs (3 pairs) are reduced. It is found in some Stomatopods (Malacostraca). The *Erichthus* arises from *Ericthoidina larva*.

Alima larva. Body is more or less like Zoea and Erichthus. Body parts are in degenerated condition. It is seen in *Squilla* (Malacostraca).

Phyllosoma larva. Body is more or less mysis-like. Transparent body has a round head and leaf-like flattened thorax with biramous appendages. The abdomen is short and narrow. This appears in *Scyllarus* and *Palinurus* (Malacostraca).

Sequences of larval appearance

In Branchiopoda, Cladocera, Ostracoda and Copepoda only *nauplius* larva appears. But in Cirripedia, nauplius stage is followed by *cypris stage* which transforms into an adult. In the *Sacculina*, after cypris another stage called *kentrogen stage* appears. In *Euphausia*, nauplius metamorphoses into *protozoea* and *calyptopis* before passing into the adult. In *Penaeus*, larvae pass through *nauplius*, *protozoea*, *zoea* and *mysis* stages, before becoming an adult. In the crabs, after certain transformations within the egg, the larva is hatched as *zoea* which changes into *megalopa stage* and then becomes an adult. In *Palinurus*, the larva hatches out in a modified mysis stage which is called *phyllosoma* larva.

Significance of crustacean larvae

It is evident that primitive crustaceans pass only through nauplius stage. More evolved Crustaceans begin with nauplius but pass through several larval stages in their life cycle, all of which resemble the primitive adult Crustaceans, i.e. *cypris*, *mysis*, etc. Such advanced Crustaceans are met within the Malacostraca. The progressive trend in the appearance of appendages, eye, segmentation and other structural organisations speaks of a distinct line of evolution in Crustacea. Thus, in spite of various limitations, it can be stated clearly from the life histories of Crustaceans that an individual in course of its development passes through stages which resemble larva of the forms which appeared during its evolution. This generalisation which was first made by Haeckel, through the studies of developmental changes in various invertebrate and vertebrate animals, is known as ***biogenetic law*** or ***recapitulation theory***.

MYRIAPODA. The larvae which hatch out, are in different morphological states in different groups. Pauropod and Diplopod larvae possess three legs. In *Julus* (Diplopoda), a pupa-like stage is present between the larvae and the adult. Within Chilopoda, in some forms (*Scutigera* and *Lithobius*), the larvae possess seven pairs of legs and reduced number of ocelli and antennal joints, but in others (*Scolopendra* and *Geophilus*) the larvae appear with full set of appendages.

Thus in all the Myriapods, larvae hatch out with all the adult structures which remain either incomplete or rudimentary. In course of transformation from larva to an adult, the complete appearance of these structures and establishment of sexual maturity occur. This type of transformation is called *anamorphosis*.

INSECTA. All the three types of development (direct, incomplete and complete) are seen within the insects.

The direct development is seen in primitive insects like *Lepisma* where the young, which comes out of the egg, resembles the adult in all respects. It grows only in size by replacing its old skin through a process called moulting.

The indirect metamorphosis is seen in less primitive forms like cockroaches and grasshoppers. Here the young which comes out of egg resembles the adult but many adult structures, i.e. wings, are lacking in them. These youngs are called *nymphs*. They lead an independent life and grow through several moultings. In many insects, e.g. Mayfly and Dragon fly, the nymphs are aquatic. When these nymphs are ready to be adult they come out of water and adult winged forms are released. No further moulting takes place after the formation of wings, only exception is Mayfly where winged form comes out of aquatic nymph and rests on a tree to undergo another moulting to become an adult. Many insects live for longer period as nymphs and the adult stage is short, the chief purpose of which is multiplication. The best example is the Mayfly where adult stage lasts only for a day but nymphs take one year to grow.

From the egg-nymph-adult cycle of incomplete metamorphosis, it is evident that insects which are advanced from the primitive *Lepisma*-like forms, have started to explore two types of environments. But success in such attempts is achieved in forms with complete metamorphosis. This climax of double life has been attained through a cycle of egg-larva-pupa-adult; larva existing in an altogether different environment than the adult. Nearly 87% of known insects develop through this cycle which involves two changes of form—one is from egg to caterpillar and the other, from caterpillar to pupa and the adult.

In the forms with complete metamorphosis, larva which comes out of egg, has no similarity with the adult. In the order Diptera, the larva is worm-like and devoid of head and appendages. It is called *maggot*. In the case of beetle they are called *grubs*. In the Lepidoptera, the larva is known as *Caterpillar*, which possesses a distinct head without eyes, numerous legs, biting mouth parts and thus completely disagrees with the adult. The caterpillars are often with protective colour or defensively shaped. These larvae eat voraciously and after some time are transformed into a stage called *pupa*. Pupa is usually immobile and remain placed within a covering but in the case of insects like mosquito, the pupa is very active. After a period of pupal existence, the young insect emerges out by breaking or dissolving the pupal case.

The independent larval forms thus explore a new environment and through voracious eating accumulate energy for the use of the adult. Also through their defensive structures, the caterpillars can win over many enemies and thus prolong their longivity.

In recent years considerable amount of work has been done to understand these events of metamorphosis. It has been found that at the time of early development, in the developing egg the cells are segregated in two groups—one group for working at the larval life and the second group to take charge during pupal and adult life. In a growing larva, the larval cells increase only in size but never undergo division. The second group of cells called *imaginal buds* remain inactive in the body of larva. When the larva is full-grown, second group of cells take over the charge. Within the apparently inactive pupa tremendous activities go on at cellular level. Imaginal buds grow by division. The larval cells die and are used up by the imaginal cells. In certain insects, within

larva, pupal cells become fluid in consistency and imaginal cells continue to form adult structures. It has also been determined that a pair of glands along the sides of the brain, known as *corpora allata* secretes a hormone called *juvenile hormone* to keep the larval cells active. But after a certain period second wave of hormone sets the production of another hormone from future thoracic region which on one hand instructs to stop the flow of juvenile hormone and on the other hand triggers the imaginal buds to be active. The absence of juvenile hormone causes the death of larval cells and they are used as nutrients for the growing imaginal buds. It has been determined that the process of moulting is also under hormonal control.

CHELICERATE

The development is direct in Pedipalpi, Scorpion, Spider, Pseudoscorpions and Phalangida. In the last group, the young resemble the adult, but is white in colour. In Scorpion, development is internal and in Solifugi the internal development continues only up to the certain period.

In the Pentapods, young possesses only three pairs of appendages. Limulus larvae also possess three pairs of abdominal appendages for swimming and resemble the Trilobites. At this stage, the caudal spine remains absent. A number of moulting result into the coming out of the adult form.

The instances of complete metamorphosis are seen in mites. Here definite larval and pupal stages appear. The pupal stage is also known as *hypopial stage.*

WHY STUDY ARTHROPODA?

A student of Zoology must study arthropods for his academic interest and also for the applied importance of the group.

Academic interest. Arthropods are many and they inhabit all sorts of environment. The study of these animals therefore can help the student to understand—What are the requirements of each kind of environment and how can a living organism develop structural features to adjust with each way of life?

The long history of these animals on the earth, specially the study of forms like Peripatus and *Limulus* provide an excellent opportunity to understand the process of evolution. Variation which is considered as the essential theme of life, may be well studied from insects specially butterflies, moths and beetles. Our understandings of ecological niches, interdependence of living organisms and biological rhythm have largely come from the study of Arthropods. Recent developments of genetics and embryology are largely based on the work done on Arthropods like *Drosophila* and Chironomous larvae. To summarise, it may be said that the study of Arthropoda is essential to understand taxonomy, evolution, embryology, ecology and genetics.

Applied interest. No other phylum is so much associated with the human life as the Arthropods. Numerous members of the group are considered *injurious* and many are *beneficial* to man to such an extent that it is assumed that if all the Arthropods are eliminated from earth the human population will also be destroyed.

INJURIOUS ARTHROPODS. The injurious Arthropods fall in two categories—(*a*) which destroy crop plants, damage stored foods and other goods, (*b*) which affects man and his domestic animals causing injury either directly or by transmitting germs of various diseases.

(*a*) *Arthropods which damage crop plants and stored articles.*

A large number of Myriapods, Insects and Arachnids eat on plant parts on which man is interested. These are commonly called *pests*. The well-known pests of paddy are *Spodoptera mauritia*, *Heliothis armigera*, *Agrotis ypsilon*, *Cirphis albistigma*, *Psalis securis*, *Nymphula depunctalis*, *Melanitis ismene*, *Schoenobius incertellus* (all belonging to the Lepidoptera), *Hispa armigera* (Coleoptera), *Leptocorisa acuta*, *Ripersia oryzae* (both Hemiptera) and a few others from Diptera, Thysanoptera and Orthoptera. A large number of pests are also known in wheat (*Sesamia inferens*, *Agrotis ypsilon*, *Toxoptera graminum*), in Sugarcane (several members of the group Lepidoptera, e.g. *Argyria sticticraspis*, *Diatroea venasota*, different Isoptera, e.g. *Odontotermes obesus* and the Hemipteran insect, *Pyrilla perpusilla*), in tea plants (*Helopeltes theiovora* of Hemiptera), in jute plants (two members of Lepidoptera, *Anomis sabulifora* and *Dicrasia obliqua* and a Coleopteran insect *Apion corchoris*)

and in cotton (several Lepidoptera like *Earias fabia*, *Platydera gossypiella*, *Sylepta derogata*, two Coleopteran insects, *Pempheres affinis* and *Sphenaptera gossypii* and one Hemiptera, *Dysdercus cingulatus*).

The stored food grains are commonly affected by insects like *Calandra oryzae*, *Tribolium castaneum*, *Rhizopertha dominica* and *Ephestia kuhniella*. Several other insects like cockroaches, ants, beetles, several kinds of moths and termites damage stored foods and different articles like clothes, books and furniture.

(*b*) *Arthropods which damage the health of man and his domestic animals.*

The arthropods may affect the health of man either by direct attack or by transmitting germs of various diseases. Such arthropods may be grouped into following categories—(*i*) Permanent ectoparasites—Arthropods which spend entire or major part of their life cycle on the external surface of the host, e.g. *Pediculus humanus* (Anoplura, Insecta), *Pulex irritans* (Siphonaptera, Insecta), *Demodex folliculorum* (Acarida, Arachnida). (*ii*) Obligatory endoparasites—Some arthropods pass only certain stages of its life cycle as endoparasites, e.g. larval stages of insects belonging to the family Gastrophilidae and Oestridae (both Diptera). (*iii*) Temporary ectoparasites—These arthropods attack man and domestic animals for food but live a free-living life, e.g. Mosquito and other Dipteran insects; *Cimex*, *Triatoma* and *Rhodinus* (all Hemiptera) and the Arachnids belonging to the family Ixodidae (Acarida). (*iv*) Poisonous forms—Several Arthropods possess various structures for offence and defence. Such structures often cause considerable damage to man, e.g. Poison spine of spider (Arachnida). Sting of Honey bee, Wasps (Insecta), Hairs of Caterpillar (Lepidoptera, Insecta). (*v*) Transmitter of diseases—The transmission of diseases is caused either *mechanically* by different Arthropods or *biologically* by permanent and temporary ectoparasites. The best examples of mechanical transmission are house fly, cockroaches, spiders which contaminate foods or drinks by various germs, Typhoid, Cholera, etc. which are carried on the legs and other body parts. The diseases like Malaria, Sleeping sickness, Chagas disease and Bubonic plague are the results of biological transmission of germs by different insects.

Beneficial Arthropods. Arthropods which are beneficial have great commercial value. They serve as food, clothings and apparels, utilitive articles, pollinating agents and also agents for controlling injurious arthropods. The crustaceans like prawn, lobster, crab and shrimps are regarded as delicious foods. A large number of Crustaceans which live as plankton serve as the food of fishes which in turn are the foods of man. Numerous birds and also several mammals are insect eaters. Man gets honey from honey bee, silk from silk worm and lac from lac insects. Honey bees, Butterflies, Moths and several other insects are well-known pollinating agents and help in increased production of crops and other plant products. Numerous Insects, Arachnids, Diplopods are insect eaters and they serve us by destroying many injurious Insects and Arachnids.

From our knowledge of arthropods we have learnt the handling of injurious and beneficial insects. Numerous chemicals like BHC (Benzene hexachloride), DDT (Dichloro Diphenyl trichloroethane), TEPP (Tetraethyl pyrophosphate), Arsenic compounds and Carbon disulphide are in our hands to control the injurious forms. Several improved techniques are now known to increase both the quality and quantity of Arthropod products like honey, shellac and silk. It has been realised that instead of indiscriminate use of insecticides it is necessary to rely more on biological controls. A number of problems are still unsolved and require further investigation.

SUMMARY

1. Arthropods are bilaterally symmetrical, metamerically segmented and jointed-legged animals. Each metamere contains a pair of appendages and a pair of nerve ganglia and each metamere is enclosed by following chitinous exoskeletal pieces—dorsal *tergum*, ventral *sternum* and lateral *pleurons*. This structural plan has changed in different forms and various types of condensation and reduction of metameres are noted.

2. Phylum Arthropoda includes largest number of animals which have occupied all possible habitats on the earth.

3. Arthropods are primarily included under

following groups—Crustaceans, Myriapods, Insects, Xiphosurids and Arachnids. The Trilobites include a group of fossils, which represent primitive arthropods. The Crustaceans, Myriapods and Insects are considered as Mandibulates and the Xiphosurids and Arachnids are called Chelicerates. The Onychophores, Tardigrades and Pentastomids are the Arthropods having uncertain systematic position.

4. The Crustaceans are Arthropods having two pairs of antennae. All of them (excepting *Oniscus*) are aquatic. The well-known forms are prawn, crabs, hermit crab, *Squilla*, etc. The head or cephalic region is distinct and is united with at least some segments of thorax to form cephalothorax. The exoskeletal covering of cephalothorax is known as carapace, which is hard in certain forms. In the primitive Crustaceans the thoracic appendages are all alike and are concerned with locomotion and food capture. But in advanced forms structural differentiation of appendages according to the function are noted. The varied condensation of metameres in different groups have led to considerable modification of different systems and specially in nervous system. Most important sense organ is the eye, which is compound in nature. It is usually mounted on movable jointed stalk. Exoskeleton contains calcareous deposits. Malpighian tubules are usually absent. Reproduction is sexual. All are oviparous. A number of larval forms are known. Parthenogenesis occurs in many Crustacea. Regeneration of certain parts are also seen.

5. Myriapods have bodies differentiated into head and trunk. The trunk is not differentiated into a thorax and abdomen. Each trunk segment bears either one or two pairs of legs. Eyes are normally simple. Respiration by simple trachea. Always lives in humid places. Reproduction is sexual. Usually oviparous and development is direct.

6. Insects constitute the largest group among the arthropods. The well-known examples are Cockroaches, Grasshopper, Butterfly, Honey bee, Silk worm and Bed bug. Head, thorax and abdomen are distinct. The head is well formed with a terminal mouth. Exoskeletal sutures of head are distinct. The cephalic appendages include one pair of antennae and mouth parts. Thorax has three segments—prothorax, mesothorax and metathorax, each having a pair of legs as paired appendages. Usually two pairs of wings as non-appendicular structures are present on the dorsal side of the thorax. Abdominal segments are often reduced by fusion. Some of the abdominal appendages have taken part in the formation of external genitalia. Adults usually do not possess paired abdominal appendages for locomotion. Nervous system exhibits varied types of condensation. Eyes are compound and sessile. Simple eyes, when present, are in degenerated state. Development may be direct or accompanied by complete or incomplete metamorphosis. Respiration is tracheal which in aquatic forms may be modified as gills.

7. Xiphosurids include panchronic animals like *Limulus*. The cephalothorax includes postoral appendages which are known as chelicerae, pedipalpi and walking legs. Antennae are absent. Abdomen is small and movably articulated with cephalothorax. A long pointed caudal style is present. Dorsal exoskeleton is thick and hard. Two types of eyes—simple and compound are present. Respiration is carried out by special respiratory organs called book gills. These animals are effective diggers. Reproduction is sexual. Oviparous forms with definite 'Trilobite' like larva.

8. Arachnids are chelicerate arthropods, having a body adapted for life on land. It includes forms like Scorpion, Pseudoscorpions, Spiders, Dady long legs, Ticks and Mites. Body is divisible into cephalothorax and abdomen. Mouth usually remains inside a pre-oral chamber. Only able to take liquid food. Respiratory organs in the form of book lungs and tracheae. Usually oviparous or ovoviviparous. Development is usually direct.

9. Peripatus exhibits organisation which has a few annelid features. Some characters resemble the arthropods but most features are unique to this group. It is considered as a living fossil.

10. Arthropods are important group of animals. Its study is essential for the very existence of man himself. It includes both injurious and beneficial forms and life of arthropods helps us to understand many basic principles of Biology.

CHAPTER 17

Phylum Mollusca

While moving on sea-beach one is struck by the abundance of varied and ornamental shells of Molluscs (Fig. 17.1). Molluscs constitute a major group in the animal kingdom and as regards their number (about 100,000 living species) and varieties, they occupy a rank almost next to Arthropods. They are distributed in all possible environments excepting aerial and exhibit many adaptive features. This chapter deals with the biology of a few typical representatives of the phylum and their adaptive features.

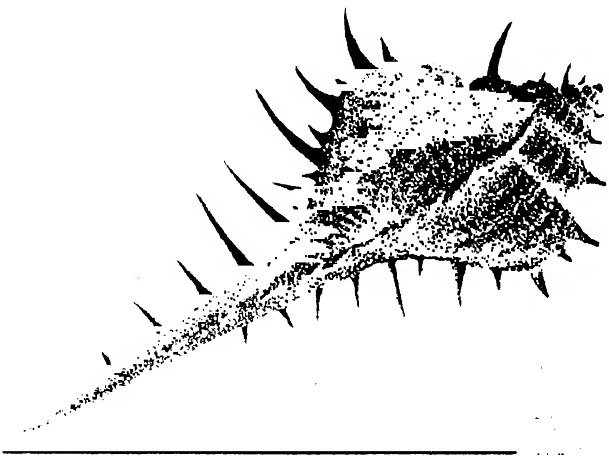


Fig. 17.1. Ornamental shell of a mollusc, *Murex*.

IMPORTANT FEATURES

The members of the Phylum Mollusca exhibit wide range of structural diversities. They constitute a very specialised group and have the following diagnostic features: (1) Majority of the members are aquatic and a few are terrestrial. (2) They possess soft and unsegmented body in the adult stage. (3) The exoskeleton, in the form of shell, is present in majority of them. The shell is mostly located externally, although a few forms with internally disposed shell are recorded. (4) Cephalization is well marked. Tentacles and sense organs are present in most of the members excepting Bivalves. (5) The visceral mass is enclosed by a thick muscular fold of the body wall called *mantle*. (6) A special structure named *radula* is present in most forms to assist in feeding. (7) Locomotor organ in the form of ventral muscular *foot* is present, which may be secondarily modified. (8) The respiratory organs are seen as specialised structures like *ctenidia* and *pulmonary sacs*. Either one kind of above respiratory structures or both may be present in an individual. (9) The excretory organs include a pair of kidneys or nephridia or organs of Bojanus. (10) The sexes are usually separate and a few forms are hermaphrodite.

CLASSIFICATION IN OUTLINE

The phylum Mollusca has been divided into six classes. The classes are: *Monoplacophora*, *Amphineura*, *Scaphopoda*, *Bivalvia* (*Pelecypoda*), *Gastropoda* and *Cephalopoda*. Morton and Yonge (1964) have classified the Phylum into six classes mentioned above. Such division of Mollusca into six classes is accepted in most modern books, but the division of the classes into smaller subdivisions remains still controversial.

Example of the Phylum Mollusca—*Chiton*

The subclass Polyplacophora is represented by a group of marine molluscs, generally called Chitons. There are many species under the genus *Chiton* and all of them have a basic structural organisation.

Habit and Habitat

Chitons are very slow moving molluscs. They usually live in shallow water and are distributed in the rocky shores. Some of the members belonging to the family *Lepidopleuridae* live in deeper zones. They are nocturnal animals and remain concealed under rocks during daytime. They have the habit of rolling up their bodies like that of Diplopods. They are herbivorous.

External structures

Chiton has an oval and dorso-ventrally flattened body. The dorsal side is convex and the ventral side is flattened. The middle portion of the dorsal side is covered over by eight overlapping pieces of calcareous shells arranged antero-posteriorly

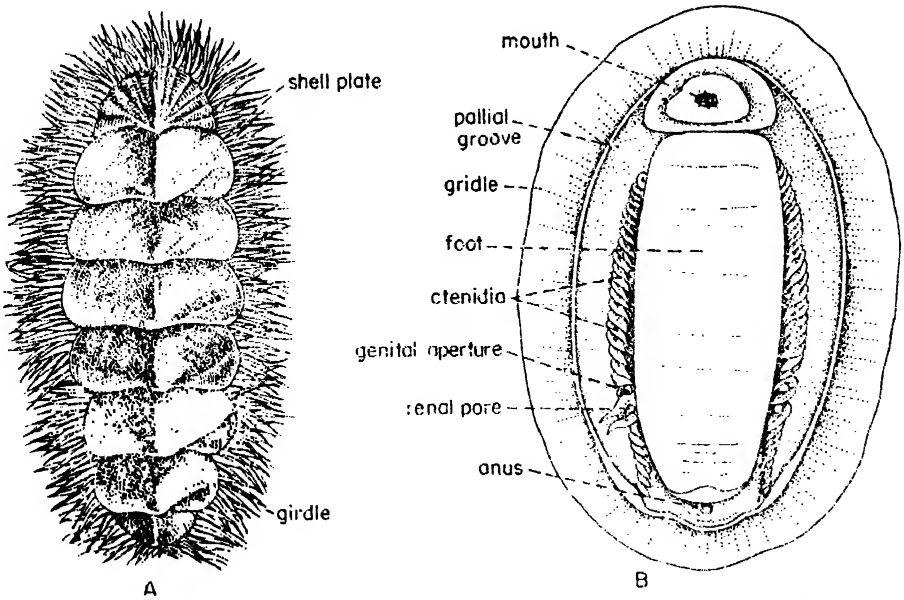


Fig. 17.2. A. Dorsal view of *Chiton*. B. Ventral view of *Chiton*. Please note the flat ventral foot.

(Fig. 17.2A). These pieces are called the *valves* or *shell plates*. The valves are arranged in an imbricate fashion and are movably articulated with one another. All the eight shell plates are encircled by the *mantle* margin like a girdle. The width of the *mantle girdle* varies in different species. This girdle is hard and contains numerous calcareous spicules, scales and spines. The ventral side of the mantle girdle is comparatively soft and contains less calcareous elements. The ventral surface of the body is occupied by a broad elliptical *foot* (Fig. 17.2B). The foot may be long and narrow in certain species as in *Cryptoplax*. The head is inconspicuous and is situated in front of the foot. The head is separated from the foot by a groove. The head bears a centrally placed mouth, but the eyes and tentacles are absent. A deep groove, present on the ventral side between the foot and the mantle, is called *mantle groove*. This groove contains external gills of variable number. The genital ducts and the excretory ducts open into the postero-lateral part of the mantle groove. The *mouth* and the *anus* are placed at the two extremities of the body. The anus is situated posterior to the foot and occupies a median position.

Structure of shell plates. As described earlier the shell of Chiton consists of a longitudinal series of eight pieces of shell plates. In majority of the species the valves remain in contact with each other but in *Cryptoplax* the valves remain separated. The valves in accordance with the dorsal convex side of the body, are curved. The first and the last valves are smaller and

hemispherical in outline. The rest of the valves (median valves) are almost triangular in outline. The surface of the median valves is differentiated into three triangular areas—a median and two laterals.

The shell plates are made up of two layers—*tegmentum* and *articulamentum*. The tegmentum is the outer layer and is composed of organic materials and the articulamentum is a calcareous layer. The tegmentum is absent in *Cryptochiton*. It has been suggested by many workers that an organic layer called *periostracum* is present over the tegmentum. The articulamentum is comparatively thick. The outer portions of the articulamentum covering the tegmentum of the lateral triangular regions of the shell plates, are called *insertion plates*. These insertion plates actually help in the attachment of the valves with mantle. The insertion plates usually possess *insertion teeth*.

Coelom

The primary body cavity in Chiton is not coelomic in nature. This is represented by extensive lacunae and they are filled up with blood. This cavity may best be regarded as a *haemocoel*. The true coelom or secondary body cavity is restricted to the pericardial cavity, lumen of gonad and kidneys.

Digestive system

The *mouth* is a round or oval aperture, situated at the centre of the head. The mouth leads into a very short *buccal tube* which is lined by epithelium thrown into longitudinal folds. The epithelium is composed of columnar cells with interspersed mucous cells. The buccal tube is continued into a wide *buccal cavity*. The buccal cavity is lined by circular and longitudinal muscle fibres. It bears a pair of simple *buccal glands* (Fig. 17.3) at the anterior end and the posterior end is prolonged into a blind sac called *subradular pouch*, which bears a *subradular organ* situated ventral to the radular sac. This organ is regarded as chemoreceptor and can be protruded into the mouth to test the substratum for food. There are no jaws in Chiton. The buccal cavity contains a long ribbon-like *radula*. The radula is enclosed by connective tissue sheath and contains transverse rows of teeth. Each transverse row contains 17 teeth having a central tooth, flanked by eight teeth on each side. The teeth are very hard and composed of dentine and instead of enamel are covered by iron. The buccal cavity leads into a short *pharynx* which produces two glandular diverticula, one on each side. These glandular diverticula are called *pharyngeal*

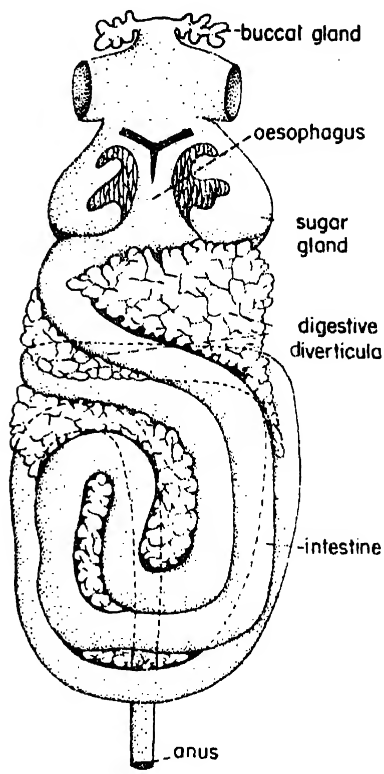


Fig. 17.3 Showing the digestive system of *Chiton* (after Parker and Haswell).

glands and have the same histological picture as found in the buccal glands. The pharynx continues posteriorly as a narrow *oesophagus* and receives ducts from two large *salivary glands*. The salivary glands are designated now as the *sugar glands* which discharge amylase (carbohydrate splitting enzyme) into the oesophagus.

The oesophagus leads into a large *stomach*. The stomach assumes various shape in different species due to the pressure of the voluminous *digestive diverticula* or *liver*. These glands have lobulated structures and they surround the stomach (Fig. 17.3). They occupy the spaces between the coils of the intestine. These diverticula secrete both proteolytic as

wells as cellulose-splitting enzymes. They open into the stomach by ducts. Digestion is largely extracellular in nature. The next part of the alimentary canal comprises of a long and coiled tube called *intestine* which opens to the exterior through the *anus*. The intestine is divided into two portions with a sphincter valve in between. The valve permits retention of food in the stomach, digestion and absorption at the anterior portion of the intestine and also the regulation of entry of waste into the posterior portion of the intestine in the form of faecal pellets. The anus discharges these pellets exterior through exhalant respiratory current.

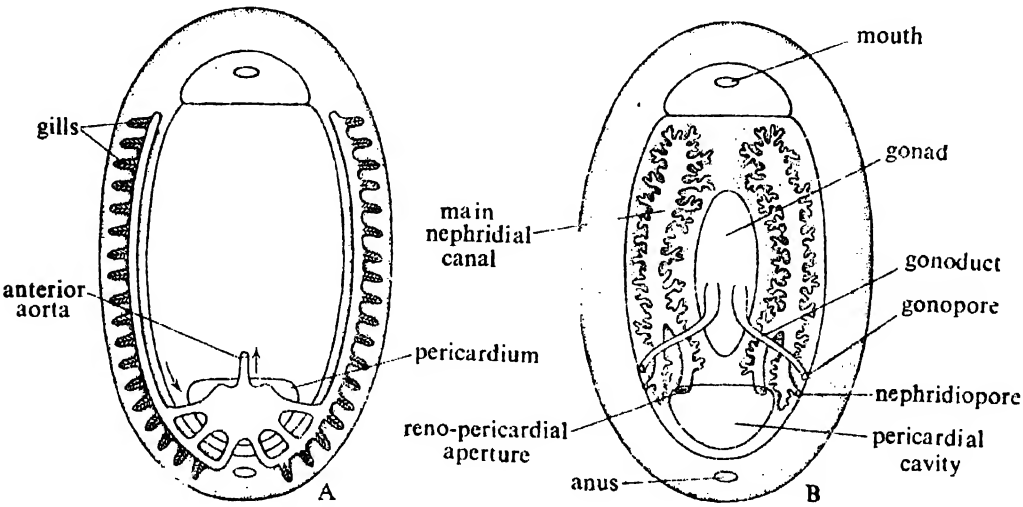


Fig. 17.4. A. Showing the relation between the gills and the circulatory system in *Chiton*. B. Excretory and reproductive systems of *Chiton* (after Kaestner).

Locomotion

Chiton creeps very slowly by the ventral foot (see Fig. 17.2B). The foot is modified for creeping movement. The movement is caused by muscular waves produced along the foot from the anterior to the posterior direction. About 15–30 seconds are required for a wave to cover the entire length of the foot and Chiton proceeds 4–8 mm by such a complete wave. Chitons can also adhere to the substratum very firmly to tide over the strong wave action of the sea.

Respiratory system.

The respiratory system of Chiton includes small external gills of variable number. The number varies from 6 to 88 pairs. The number of gills are not constant feature of a species but the number increase with the increase of size of the body. The gills are arranged in the mantle groove (Fig. 17.4A). The mantle groove is divided into two narrow chambers by a continuous curtain of gills on either side. One chamber is designated as the inhalant chamber while the other is called exhalant chamber. The inhalant chamber is located between the gill row and girdle and the exhalant chamber is located between the edge of the foot and the inner side of the gill row. A single gill has two series of flat and oval lamellae arranged on a central axis. The lamellae are lined by ciliated epithelium. The gills may extend the whole length of the body (holobranchiate type) or may be restricted towards the posterior end of the body (merobranchiate type). The holobranchiate types of gills are present in most cases, but merobranchiate types are present in a few forms like *Schizochiton*, *Lepidopleurus*.

Circulatory system

The circulatory system consists of the pumping organ *heart*, *arteries*, *sinuses* and *blood*. The blood of some Chitons contains a soluble respiratory pigment (haemocyanin) and corpuscular elements. The heart consists of a median tubular *ventricle* and a pair of lateral *auricles*. They are located in the pericardial cavity which is filled with a proteinaceous liquid.

The *pericardium* is situated beneath the last two shell plates and its dorsal wall is fused with the dorsal body wall. The ventricle gives off a *median dorsal aorta* which supplies blood to the different parts of the body. The head contains a blood sinus of arterial nature. This sinus is called the *head sinus*. From this sinus an arterial channel called *visceral artery* proceeds posteriorly and ramifies in the viscera. From the viscera venous blood is collected in the *visceral sinus*. The head sinus also gives off several longitudinal channels on the posterior side. Of these channels, the important ones are the paired *pedal sinuses* and *paired neuropedal sinuses*. Besides these, there are a few more sinuses called the *neurolateral sinus* and the *afferent* and *efferent branchial sinuses*. The *median longitudinal sinuses* of the foot primarily receive most of the venous blood. This blood is communicated to the afferent branchial sinus by large *transverse sinus*. After oxygenation the blood is collected by efferent branchial sinus. From the efferent branchial sinus most of the blood returns to the auricle by a number of apertures called *auricular pores*.

The arrangement and number of the longitudinal sinuses vary in different forms of Chiton. The important variation is the absence of visceral artery in most cases.

Excretory system

The excretory system consists of two slender symmetrically placed kidneys (Fig. 17.4B). Each kidney is more or less a Y-shaped tube. The single long limb of the 'Y' constitutes the main body and ends blindly at the anterior side. This tube receives numerous minute tubules that ramify in the viscera. The two shorter limbs have openings, one is the *nephridiopore* situated near the genital pore and the other opens into the pericardium through a ciliated aperture called *reno-pericardial aperture*.

Nervous system

The nervous system of Chiton is very simple and consists of a *circumenteric nerve ring* which is divided into an anterior cerebral half (*cerebral commissure*) and a lower thin buccal part which gives rise to the *buccal* and *subradular connectives*. The *buccal ganglia* are connected by *buccal commissure* on the dorsal surface of the buccal cavity. The cerebral half is thicker, lacks ganglia and gives off posteriorly two pairs of descending nerve cords, the *pedal* and *pleural* (or *palliovisceral*) *nerve cords*. The pedal cords innervate the musculature of the foot and the palliovisceral cords send nerves to mantle and visceral organs. Both the nerve cords are connected by transverse nerves. Pedal nerve cords are free posteriorly whereas the pleural nerve cords are joined posteriorly to form *suprarectal commissure*. Such ladder-like arrangement of the nervous system reflects primitive organisation (for diagram see Fig. 17.59G in the general notes on the phylum in the last part of this chapter).

Sense organs

Specialised sense organs are lacking in Chiton. Elongated *neurosensory cells* with terminal bristles are quite abundant.

Gustatory organs. They are situated in the floor of the buccal cavity. These organs are composed of sensory and supporting cells.

Subradular organ. The subradular organ is regarded as chemoreceptor. It is one in number and situated on the posterior end of the subradular pouch.

Sensory epithelium. There are patches of sensory epithelium in the pallial groove and these are said to be homologous with osphradia.

Aesthetes. The tegmentum of shell plates is perforated by numerous canals which are provided with many light sensitive (photoreceptors) and tactile organs (tactoreceptors). These organs are known as *aesthetes*. Aesthetes are divided into two types according to size—*megalaesthetes* and *micraesthetes*. The dorsal surface of Chiton is sensitive to light and tactile stimuli. They are innervated by the lateral nerve cords. A megalaesthete has a slender core of elongated sensory cells surrounded by glandular cells. These two components are surrounded by an epidermal layer which is continuous with the nerve cords. The non-nucleated strands emerging from the megalaesthetes are called the micraesthetes. Both of them ascend vertically to the surface through tegmentum and terminate in a hard cap. The caps of the megalaesthetes are called megalopores and those of micraesthetes are called the micropores.

In some forms of Chitons, few micraesthetes assume the form of eyes with cornea, lens, pigmented layer and retina (Fig.17.5).

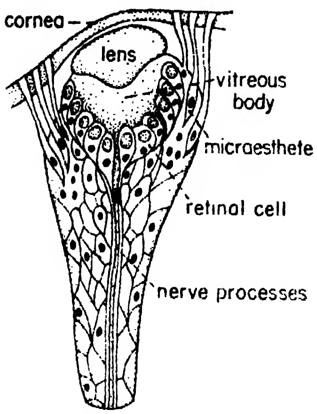


Fig. 17.5 Showing a micraesthetes and an aesthete eye of *Chiton*.

The number of eyes in a few species are enormous. In *Acanthopleura echinata* the total number of eyes present on the valves are estimated to be 11,500. The number of micraesthetes present on a single megalaesthete vary from 20 to 25. In some cases micraesthetes may be absent.

Reproductive system

The sexes are separate. The testis and ovary are more or less similar in appearance. The gonad is placed on the dorsal side in front of the pericardium and above the intestine. The gonoducts are two and each opens into the mantle groove in front of the excretory aperture (Fig. 17.4B). In almost all the forms excepting *Nuttalochiton hyadesi* and *Notochiton mirandus*, the gonad is single and is medially placed.

Development

Fertilization occurs in the mantle cavity. In *Callistochiton viviparus*, a viviparous species, entire development of the young takes place in the female gonoducts. Segmentation is complete and occurs typically in spiral fashion. At the eight-cell stage, four small upper tiers of cells called *micromeres* are produced and the lower four cells are called *macromeres*. Each macromere then gives origin to three micromeres which transform into *ectoderm*. The macromeres gives rise to the *endoderm*. The *mesoderm* emerges from the cells originating from the posterior macromeres. Both micromeres and macromeres arrange themselves in such a way that a flattened *blastula* with *blastocoel* is produced. Gastrulation occurs typically on an embolic fashion, i.e. by the inpushing of cells.

By subsequent embryological changes a fully-formed larva is formed which comes out of the egg envelope. This larval form is called *Trochophore larva*. It resembles closely the trochopore larva of Annelida (see Fig. 15.12). It has an oval body with prototroch, apical sensory tuft of cilia, a pair of eyes below the prototroch and primitive archenteron. The trochophore larva after coming out from the egg envelope swims in water for a period varying from 15 minutes to a few days according to species. The larva then sinks to the bottom and undergoes metamorphosis. The first noticeable change is the dorsoventral flattening of the body of larva. The prototroch, eyes and the apical tuft of cilia are lost and a young Chiton is formed which attains adult morphology in due course.

EXAMPLE OF THE PHYLUM MOLLUSCA—*UNIO*

Unio marginalis (Fresh-water mussel) is a typical representative of the class Bivalvia. It belongs to the family *Unionidae*. There are several genera under this family of which the genus *Unio* is widely studied.

Habit and Habitat

Unio is an aquatic form and inhabits fresh-water lakes, ponds and rivers. They usually burrow in the mud at the bottom of the pond by their large ventral *foot*. They do not go deep in the burrow, because the posterior extremities of the valves is to be kept exposed for the ingress and egress of respiratory water current. They usually stay in shallow water during night, but migrate to deeper water during daytime. The food of Unio comprises of microscopical plants and animals.

External structures

Unio has a bilaterally symmetrical body and the size varies from about 5 to 10 cm in length. The body is laterally flattened. The anterior side of the body is roughly oval in outline and the posterior end is slightly narrower. The body is

enclosed by a hard calcareous *shell* (Fig. 17.6A) which consists of two equal valves hinged at one edge. Beneath the shell, a delicate layer called *mantle* envelopes the whole visceral mass. The mantle has two epithelial layers with an intermediate connective tissue layer (Fig. 17.7). The epithelium just beneath the shell is composed of secretory cells and the inner epithelium is ciliated. The mantle shell respectively (Fig. 17.6B). The scar mark of the *anterior adductor muscle* is slightly smaller than that of the posterior one. Impressions of the anterior *retractor* and *protractor muscles* of the foot are present near that of the anterior adductor muscle. Another small impression of the posterior *retractor muscle* lies near that of the posterior *adductor muscle*. A streak known as the *pallial line*, produced by the insertion of

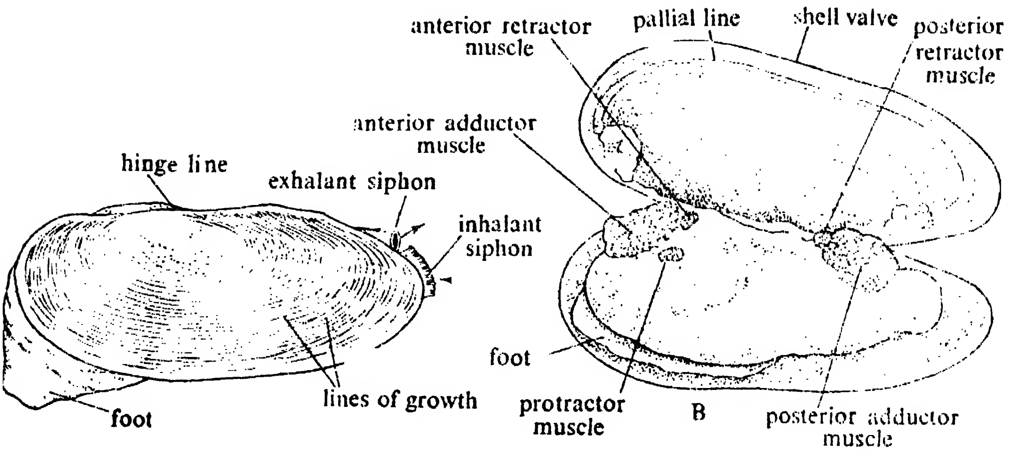


Fig. 17.6. External features of *Unio*. A. Side view of an entire animal. The head of the arrow indicates the direction of water current. B. Internal structures of *Unio* after partial removal of the left shell valve.

consists of two lateral halves called the *mantle lobes*. The mantle lobes at the aboral side produce two short tubes—the *inhalant* and *exhalant siphons*. The edge of the exhalant siphon is smooth and that of the inhalant siphon is produced into delicate processes. Sometimes the triangular tongue-shaped foot protrudes between the two valves towards the oral end.

Macroscopic structure of shell

The two valves are united dorsally along a *hinge-line* by elastic *hinge-ligament* which helps the opening and closing of the valves. The *hinge-teeth* are present in Unio. The teeth are so arranged that the teeth of one fit into the sockets of the other valve. Series of concentric *lines of growth* are present on the external surface of the shell. The lines of growth start from an elevation—the *umbo* which is the thickest and the oldest part of the shell. Some characteristic markings are also observed on the inner side of the shell. Two large oval impressions of the anterior and posterior adductor muscles are present near the anterior and posterior ends of the

muscular fibres of the mantle into the shell is present.

Microscopic structure of shell

The shell has three distinct layers (Fig. 17.7). The outermost layer, known as

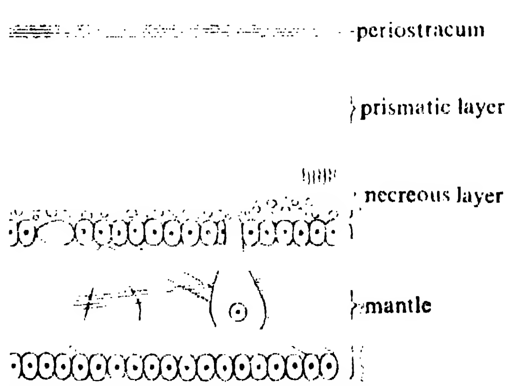


Fig. 17.7. Sectional view of the shell and mantle in *Unio* (after Borradaile & Potts).

periostracum is composed of a substance, related to chitin, called *conchiolin*. Beneath the periostracum is the *prismatic layer*

formed of alternate layers of conchiolin and prisms of calcium carbonate. The innermost layer, called the *nacreous layer* is formed of alternate linings of conchiolin and calcium carbonate. Such linings are arranged parallel to the surface.

Coelom

The original coelomic cavity, in an adult, is replaced by connective tissue and is represented by three small cavities—the pericardium, the cavities in the gonads and the cavities in the excretory organs. The general body cavity is a *haemocoel*.

Digestive system

The digestive system includes alimentary canal and digestive glands (Fig. 17.8). The mouth is a transverse slit and situated below the anterior adductor muscles as a slit. It is bounded by two pairs of conical flaps called the *labial palps*. One pair of labial palps are external and the other are internal. The external labial palps in front of the mouth unite to form the upper lip and the internal labial palps similarly unite behind the mouth to form the lower lip. The *radula* is absent in Unio. The mouth leads into a spacious sac-like *stomach* by a short *gullet*. A pair of irregular *digestive glands* (*liver*) surround the stomach and the secretion of the gland is poured into the stomach by small ducts. From the posterior end of the stomach starts the *intestine* which enters into the visceral mass and forms coiled loop. The intestine then goes up and takes the level of the stomach. It then proceeds towards the posterior end through the pericardium and ventricle of heart as the *rectum*. It finally opens into exhalant siphon as *anus*. The rectal portion of the intestine is provided with a longitudinal ridge known as the *typhlosole* which forms two longitudinal grooves, one on each side. The typhlosole increases the absorptive area of the intestine. From one of such grooves of the intestine, a gelatinous rod-like structure known as *crystalline style* projects into the stomach which probably helps in the digestion of cellulose and starch. It has been seen that in starving Unio the crystalline style disappears.

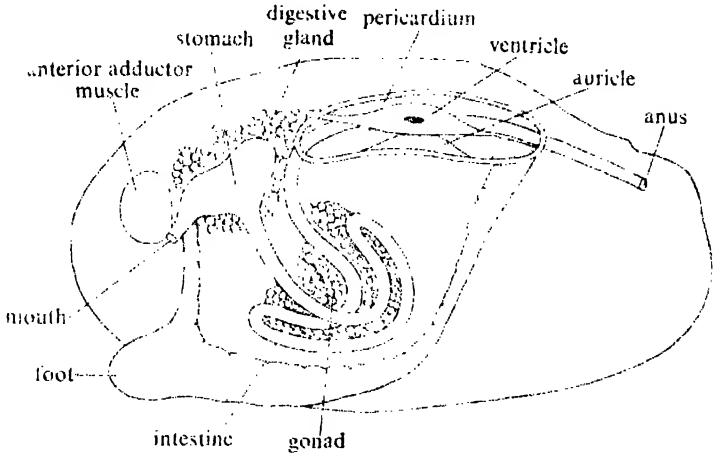


Fig. 17.8. Digestive system of *Unio*. Labial palps are removed.

Locomotion

The muscular foot is the primary locomotor organ. The foot protrudes between the antero-ventral sides of shell valves and burrows like ploughshare through the mud. During progression, due to the flow of blood into the foot, the latter swells up and becomes turgid. When the animal intends to move, the foot is extended forward as far as possible by influx of blood and its contraction draws the body forward. So by such alternate extension and contraction of the foot, the animal moves very slowly.

Respiratory system

Unio is exclusively an aquatic animal. The respiratory organ consists of two *gills* or *ctenidia* situated one on each side of the

body (Figs. 17.9 and 17.10A). Each ctenidium has an external and an internal

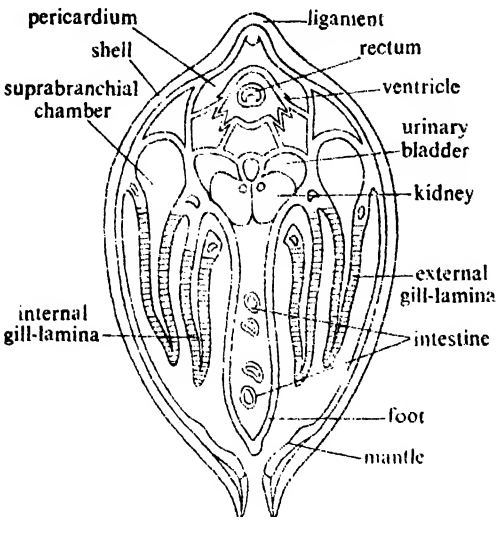


Fig. 17.9. Transverse section of the middle region of *Unio* showing the relative position of gills.

gill plates or *gill laminae* (Fig. 17.10B). Each gill lamina is a double structure formed of two similar plates, the outer and inner *gill lamellae*. The internal and the external gill lamellae are united with one another on all sides excepting the dorsal end. The spaces between the internal and external gill lamellae are subdivided by vertical bars called *interlammellar junctions* into a number of compartments called the water tubes (Fig. 17.10C). Each lamina exhibits double striations. The vertical striations are due to closely-set gill filaments that compose the lamellae. The longitudinal striations are due to the fact that these filaments are connected by horizontal *interfilamentar junctions*. Between the gill filaments, bounded by interfilamentar junctions, there are minute apertures called *ostia* opening into the water-tubes.

A transverse section of the gill filament reveals that it is covered by ciliated epithelium (Fig. 17.10E) and is supported by

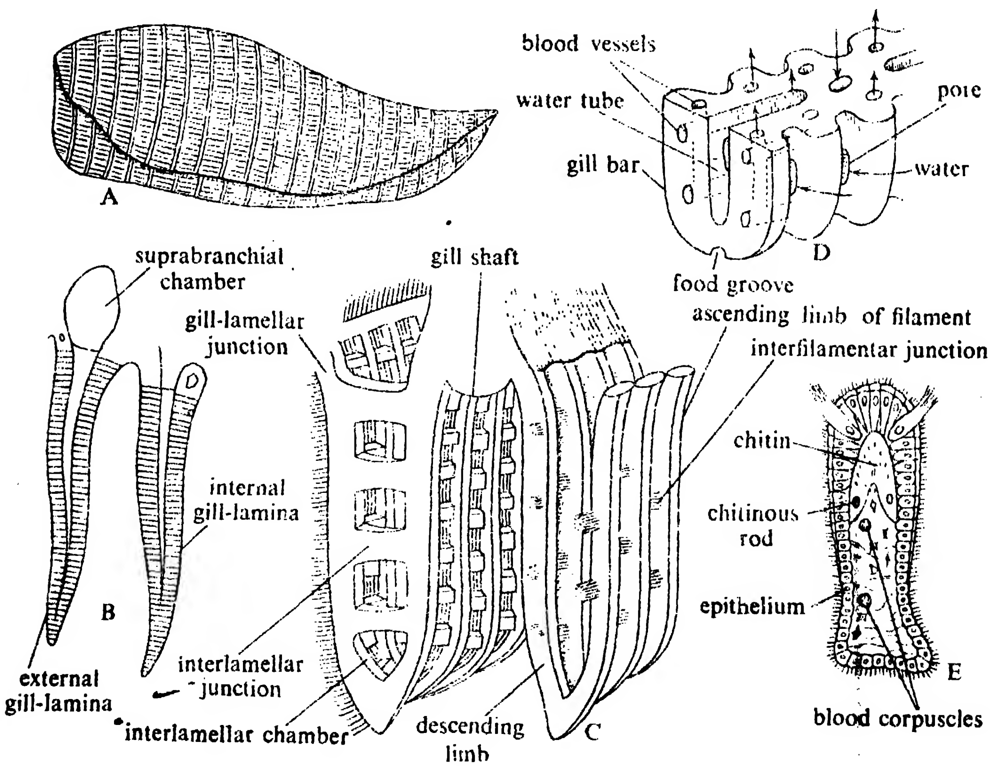


Fig. 17.10. Structure of gills in *Unio*. A. Lateral view of whole of the left external gill lamina. B. Section of a gill to show external and internal gill laminae. C. Detailed structural plan of gill lamellae. D. Enlarged view of a portion of gill showing the directions of blood flow and water current. Arrows indicate the direction of flow. The downwardly directed arrows indicate afferent and the upwardly pointed arrows indicate efferent vessels. E. Transverse section of a gill filament (after various sources).

chitinous rods. The cavity of the gill filament is filled with blood. The long cilia present in the gill filament produce a current which drives the water from the mantle to the water tubes (Fig. 17.10D). The arrangement of gills shows that the water tubes open into the *suprabranchial chamber* which continues posteriorly and opens to the exterior by exhalant siphon.

By the action of cilia, a constant flow of water-containing dissolved oxygen passes through the ostia into the water tubes (Fig. 17.10E). From the water tubes water enters into the *suprabranchial chamber* and finally goes out to the exterior from the suprabranchial chamber by the exhalant siphon. Gill filaments are highly vascular structures and during the transit of water through ostia to water tubes gaseous exchange takes place.

In addition to gills, the highly vascular mantle acts as an accessory respiratory structure.

Circulatory system

The blood is colourless and consists of *plasma* and few *leucocytes*. The heart consists of a muscular *ventricle* and two thin-walled *auricles* enclosed by *pericardium*. The auricles communicate with the ventricle. This opening is guarded by valves. Two aortae originate from the two ends of the ventricle (Fig 17.11), one is the *anterior aorta* situated above the rectum and the other is the *posterior aorta* located below the rectum. One of the peculiar features in Unio is that the rectum passes through the pericardium and the ventricle (Fig. 17.12). The aortae give rise to arteries such as pallial, gastric, pedal and intestinal arteries

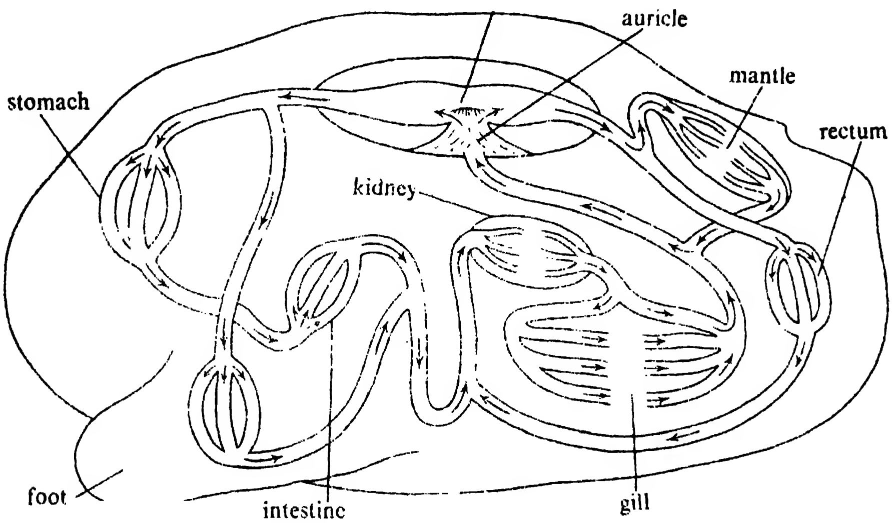


Fig. 17.11. Circulatory system in *Unio*. The head of the arrow indicates the course of circulation.

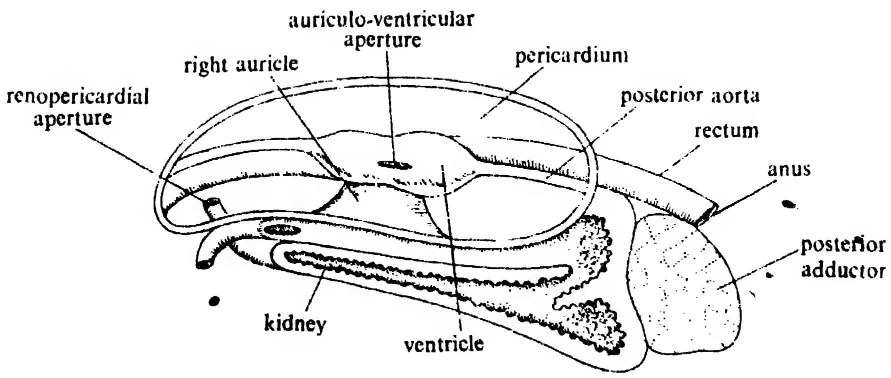
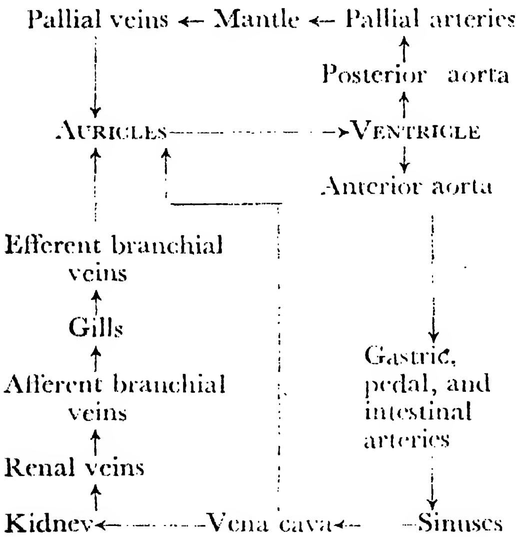


Fig. 17.12. A part of visceral mass of *Unio* showing the position of heart, rectum and kidney.

which supply the whole body. The blood from the different parts of the body is collected into a large *vena cava* located in between the kidneys. From the vena cava blood returns to the auricles by two ways. In one circuit, blood flows into the gills by *afferent branchial veins* and then returns to the auricle by *efferent branchial veins*. Before coming to the gills blood from the vena cava passes through the kidneys. The renal veins ultimately unite to form the *afferent branchial veins*. In the other circuit, blood from the vena cava comes to the auricle directly without going through the kidneys and gills. Mantle also acts as an accessory respiratory organ from where blood returns to the auricle through pallial veins.

The circulatory circuit is schematically represented below:



Excretory system

The excretory organs of Unio comprise of a pair of kidneys called the *organ of Bojanus*. These are situated one on each side of the body below the pericardium. Each kidney consists of two parts, a *glandular part* and a thin-walled ciliated *urinary bladder* (Fig. 17.12). The glandular part of the kidney opens to the pericardium by *renopericardial aperture* and the bladder opens to the exterior by a minute opening called renal aperture (*nephridiopore*) situated between the visceral mass and the inner lamina.

In addition to kidneys, a large reddish-brown glandular mass known as *Keber's organ* or *pericardial gland* is regarded to be excretory in function. It is situated in front of the pericardium and discharges the excretory products into the pericardial cavity.

Nervous system

The nervous system of Unio (Fig. 17.13) comprises of ganglia (aggregation of nerve cells), commissures (nerves connecting two similar ganglia), connectives (nerves connecting two dissimilar ganglia) and nerves. There are two *cerebral ganglia*. These are present one each at the base of labial palps just outside the corners of the gullet and are connected by a *cerebral commissure*. A bilobed *pedal ganglion*, formed by the fusion of two ganglia, is located at the junction of the visceral mass with the foot. This ganglion is connected with the two cerebral ganglia by two nerves situated one on each side of the body, called the *cerebro-pedal connectives*. Another bilobed ganglion called the *visceral ganglion* is present on the ventral side of the posterior adductor muscles. The visceral ganglion is very large in size and is connected with the two cerebral ganglia by two *cerebro-visceral connectives*, one on each side of the body. The cerebral ganglia supply nerves to the anterior and posterior labial palps and to the anterior part of the mantle. Nerves are given off to the foot and its musculature by the pedal ganglion. The visceral ganglion gives out on each side, a dorsal and a posterior *pallial nerve* to the mantle, a *renal nerve* to the posterior end of the kidney, a *branchial nerve* to the gill and a nerve to muscles of the posterior adductor and a nerve to the anterior part of the alimentary canal.

Sense organs

The main sense organs are the *Osphradium* and the *Statocyst*. The osphradium is an organ for tasting water and is present in connection with the visceral ganglion. It consists of a patch of sensory epithelium. The other sense organ is the organ of balance (*statocyst*), located near the pedal ganglion and has the nerve supply from the cerebro-pedal connective. There are two statocysts in Unio. Each statocyst is a hollow sac lined by sensory cells and a centrally placed statolith

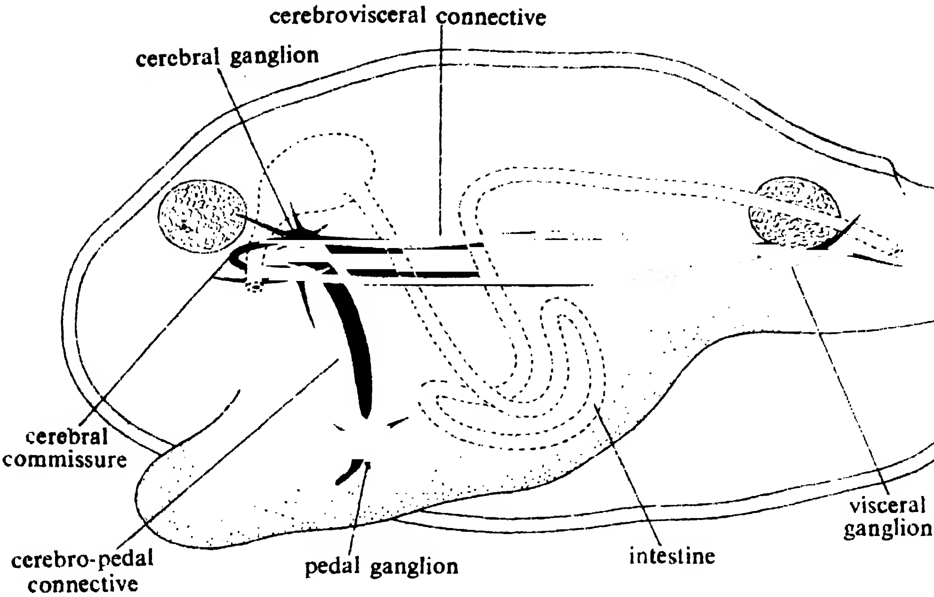


Fig. 17.13. Nervous system of *Unio*.

(Fig. 17.14). Besides osphradium and statocysts, the margin of the mantle lobes are provided with sensory cells which are probably tactile organs and photoreceptors.

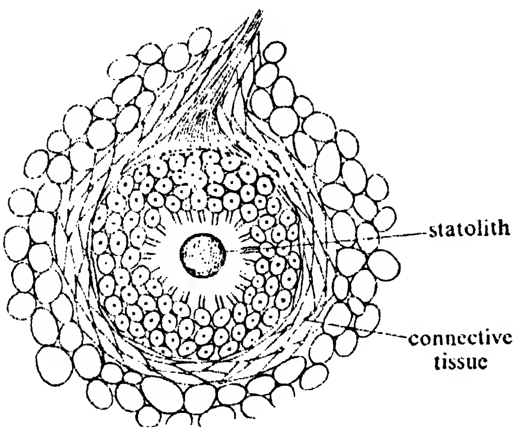


Fig. 17.14. Statocyst of *Unio*.

Reproductive system

The sexes are separate. The male gonad or testis is white in colour and the female gonad or ovary is red. Both the gonads are large paired organs occupying the major portion of the visceral mass among the intestinal coils. But Morton (1967) has claimed that the gonad is a single median organ in both the sexes. The gonads have a short duct that opens to the exterior by genital aperture located just in front of the renal apertures.

Development

Development of the zygote starts within the external gill laminae which dilates to accommodate the developing embryo. Segmentation is complete and equal. After the formation of blastula and gastrula, a larval form emerges out. It is called **Trochophore** larva (see Fig. 15.12). The trochophore larva has the same structural plan as in annelids. During development, this larval form subsequently passes on to the characteristic **Glochidium** larva. These larvae are expelled from the body of the female to water (Fig. 17.15A).

Structure of Glochidium. It has got a long bivalved shell. The valves are porous and united dorsally, but free ventrally. In a related genus *Anodonta* the free ventral ends of the valves become curved like hooks beset with many spines. Such structures are not observed in Unio. The body consists of an undivided mass which is differentiated into a single dorsally placed body proper and two mantle lobes, the right and the left (Fig. 17.15B). A glandular pouch is present on the ventral side of the body which secretes a very long thread called the provisional *byssus*. A single large adductor muscle, which arises from

the mesoderm, is present to connect the two valves. The byssus moves to and fro and attaches itself with the gills of fresh-water fishes. The glochidium penetrates the host tissue and becomes enclosed by gill epithelium. It lives there as an ecto-parasite for about two and half months (Fig. 17.15C). The provisional byssus and sense organs disappear and metamorphosis starts. The stomodaeum is formed by in-vagination of the ectoderm. Foot originates as a ventral elevation. After such development, the young glochidia detach

Habit and Habitat

Pila globosa inhabits fresh-water ponds and lakes. They are quite abundant in water having succulent aquatic vegetation on which they feed. They are really amphibious forms, i.e. they live most of the time in water but they can also thrive well on land. They exhibit two-fold respiratory adaptations. They respire in water by ctenidium and by pulmonary sac on land. During prolonged drought they may remain torpid for a long time and during rains they return to normalcy.

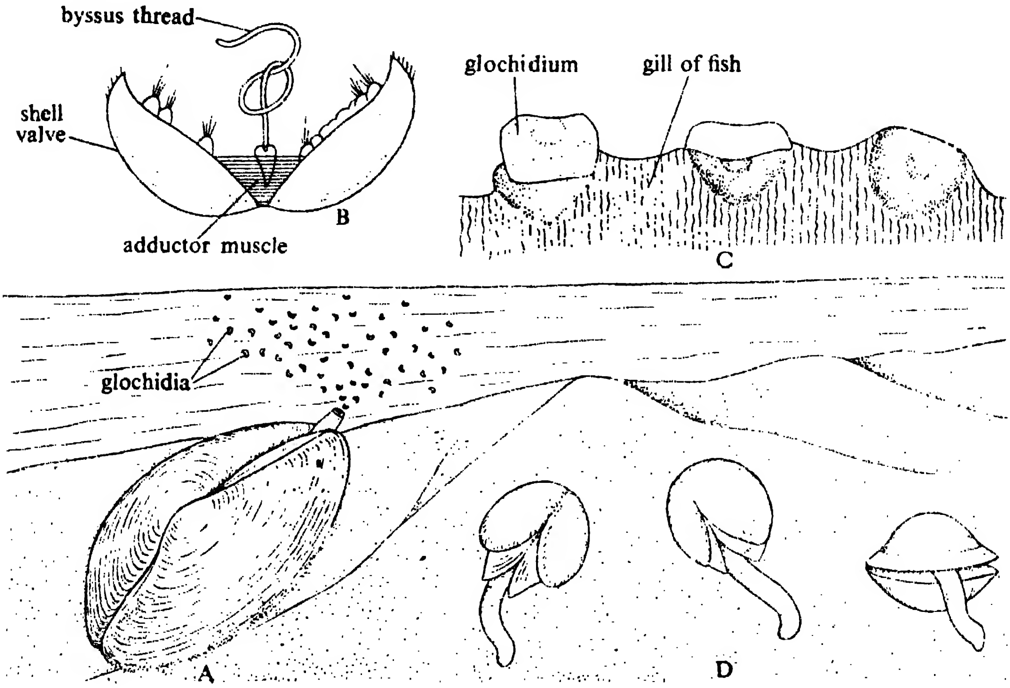


Fig. 17.15. Life cycle of *Unio*. A. Female discharging glochidia. B. Enlarged view of a glochidium. C. Penetration of glochidium and its gradual enclosure in the host gill epithelium. D. Youngs at the bottom of the pond.

themselves from the gills of fish and sink to the bottom of the water (Fig. 17.15D) and attain adult morphology.

Example of the Phylum Mollusca—*Pila*

Pila globosa is commonly known as pond snail or apple snail. It is a typical representative of the class Gastropoda. It belongs to the family *Pilidae*. The members of the family are distributed in the Oriental and Ethiopian regions of the world. The common species of the genus is *P. globosa*. It is quite abundant in the fresh-water ponds.

External structures

The body of Pila is enclosed by a thick spirally-coiled globular shell. It has the form of an elongated cone coiled round a central axis in a spiral manner. A single revolution of the shell is called the *whorl*. The extreme top of the shell is designated as *apex* (Fig. 17.16A). The *apex* of the shell is regarded as the oldest part of the shell. Starting from the apex the other whorls—the *penultimate whorl* and *body-whorl* are large to enclose the greater part of the body. The first whorl is smallest and the last one is the largest (Fig. 17.17A). The last whorl contains a large aperture,

which can be closed by a lid called *operculum* which is attached to the posterior side of the foot. The operculum is a flat calcareous plate. It is formed as a cuticular secretion of a group of cells from the foot. It has a lunate-oblong outline which corresponds to the aperture of the shell. The operculum shows numerous concentric rings of growth around a well-marked nucleus. The inner surface of the operculum shows a distinct elliptical area called *boss* for the insertion of opercular muscle (Fig. 17.16B). The margin

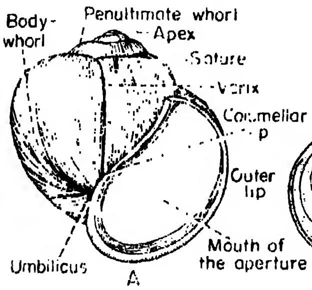


Fig. 17.16. Showing the structure of shell (A) and operculum (B) of *Pila*.

of the aperture is smooth and is called *peristome*. A spiral column arising from the centre of the shell is present on the inner side. It is called *columella* (Fig. 17.17C). The type of coiling is right-handed and is called *dextral*. In rare or abnormal cases left-handed coiling (*sinistral*) is also observed. Detailed account of coiling in gastropods is discussed in general notes on mollusca.

The microscopic picture of shell of Pila exhibits three layers. The outer layer is chitinous and known as *periostracum*. The two underlying layers, the *ostracum* and *hypostracum*, are composed of calcareous material. The periostracum is thin and consists of a large number of parallel bands in young stage. These bands are separated from one another by wavy lines. Each band is made up of rectangular blocks. But in an adult, the periostracum appears as a homogeneous membrane without showing the bands or blocks. The ostracum and hypostracum are essentially similar. The plates constituting these calcareous layers are disposed differently.

The whole body is located within the whorls of the shell and is attached to the columella of the shell by *columellar muscle*. The columellar muscle arises from the foot and is attached with the columella. The columellar muscle plays a vital role. It prevents the animal from extending out of the shell beyond certain limit and also helps to withdraw it into the shell. The body is divisible into the *head*, *foot* and *visceral mass*. The head along with the foot can be protruded to a limited extent through the aperture of the shell (Fig. 17.17A).

The head is well-marked. It is prolonged into a partly contractile *snout*. It carries two pairs of tentacles. The longer pair are thread-like and contain stalked eye at the base. The shorter pair are called *labial palps* or first tentacles and are regarded as the

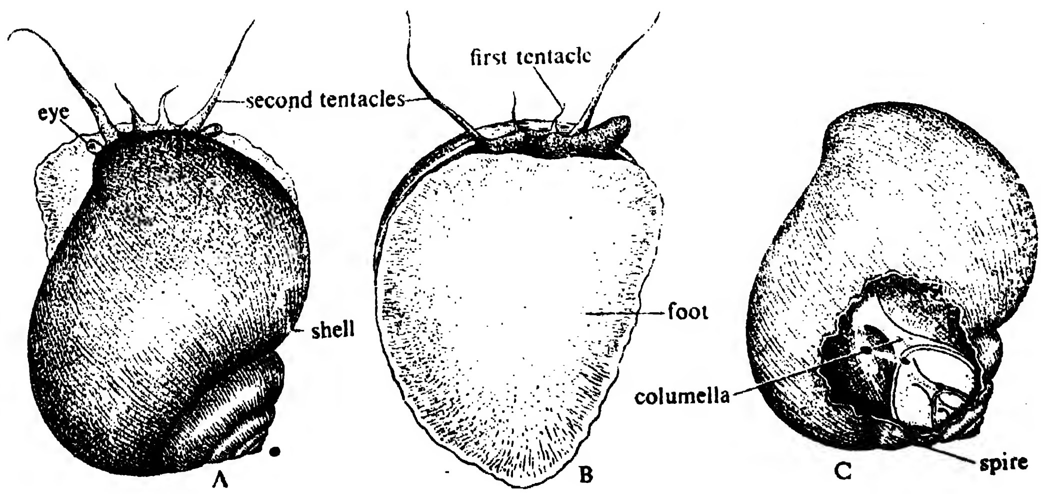


Fig. 17.17. External features of *Pila*. A. Dorsal view. B. Ventral view. C. A portion of shell is broken to show the columella.

antero-lateral prolongations of snout. Two fleshy projections, called *nuchal lobes* or *pseudoepipodia*, are seen on the two sides of the head. The lobes, although projected anteriorly over the foot, are the prolongations of the mantle and are innervated by nerves from the pleural ganglia. The left nuchal lobe is highly developed and forms the *respiratory siphon*. The nuchal lobes of Pila are not homologous with the epipodia of other gastropods.

The foot is more or less triangular when seen from ventral side (Fig. 17.17B). The anterior part of the foot is round and the posterior part of the foot holds the *operculum*. The foot is highly muscular and contains pedal glands. Pila is adapted to creeping movement.

The skin covering the visceral mass forms the *pallium* or *mantle*. It forms a cloak over the anterior part of the body including the head and its appendages in retracted state. The mantle subserves three functions in the life of Pila: (*i*) protects the visceral mass and head, (*ii*) serves as an additional respiratory organ and (*iii*) secretes the shell by the shell-secreting glands at the free margin of the mantle. The mantle is free anteriorly and encloses a spacious cavity known as *pallial* or *mantle cavity*. This cavity contains visceral organs of the animal. The mantle cavity is imperfectly divided into left and right chambers by a longitudinal ridge known as *epitaenium*. The right chamber contains the ctenidium, rectum and the genital duct. The left chamber contains the *pulmonary sac*. There is a comb-like organ of taste known as *osphradium* close to left nuchal lobe. The mouth and anus are closely situated on the same side of the body. The anal and the genital apertures are located on the right mantle opening.

Coelom

In adult, the general body cavity is a *haemocoel* as seen in other molluscs. The true coelom is represented by the pericardial cavity and the cavities round the kidney.

Digestive system

Pila lives primarily on aquatic vegetation. The digestive system is composed of digestive canal and digestive glands (Fig. 17.18). The digestive canal is distinguishable into; (*i*) *fore gut*, (*ii*) *mid gut* and (*iii*) *hind gut*. The fore gut and the hind gut possibly develop from the ectodermal layer, while the mid gut is endodermal in origin. The fore gut includes the

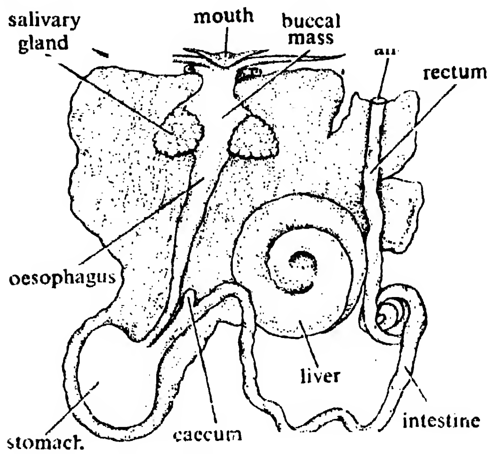


Fig. 17.18. Digestive system of *Pila*.

buccal mass and the oesophagus, the mid gut consists of the stomach and the intestine and the hind gut includes the rectum.

FORE GUT: The mouth is a vertical slit which leads into the anterior end of the digestive tract which becomes greatly swelled to form an oval buccal cavity. The buccal cavity is enclosed by a strong thick-walled muscular structure called *buccal mass*. The buccal mass is regarded as the pharynx by many workers. The entrance of the mouth is guarded by a pair of chitinous jaws projecting from the roof of the buccal cavity (Fig. 17.19A). Covering the floor of the buccal cavity, is present a chitinous ribbon-like structure. This structure is known as *radula* or *lingual ribbon* (Fig. 17.19B). It is an elongated structure bearing transverse rows of serrations. Each transverse row contains about seven teeth —two *marginals*, a *lateral* on either side of a median *rachidian* tooth, giving the formula as: 2, 1, 1, 1, 2=7. The radula is movably placed by muscles upon a large outgrowth of the floor of the buccal cavity called *tongue mass* or *odontophore*. It is made up of muscle with cartilaginous support. It has an anteriorly placed *subradular organ*. The subradular organ is a more or less rounded structure. It is divided into two by a median furrow. A small pouch like sublingual cavity is present beneath the subradular organ. The

radula at the posterior end enters into a radular sac which supplies new teeth to the radula. The radula is pushed forward by muscles from behind and it works as a file by rasping food materials. Pila is a vegetable feeder and takes leaves of aquatic weeds by cutting with the *jaws*. The buccal cavity receives two *salivary glands* on the posterior side.

The buccal cavity leads into *oesophagus*. The oesophagus is a long tube and just after its origin from the buccal mass it gives out on each side, a small outpushing called *oesophageal pouch*. The oesophagus ends in *stomach*.

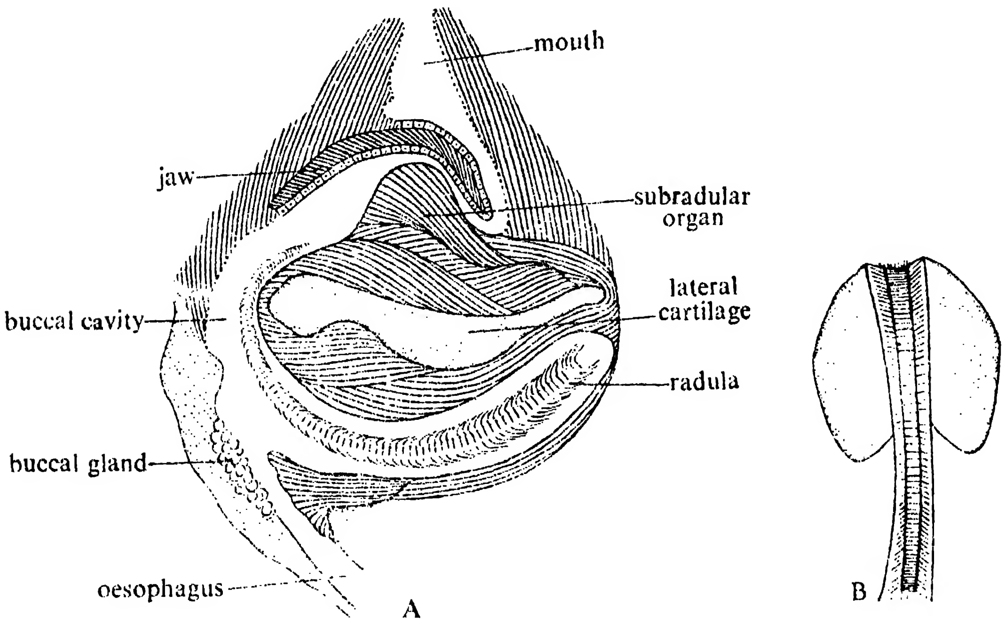


Fig. 17.19. A. Sectional view of buccal mass of *Pila*. B. Radula of *Pila*.

MID GUT: The stomach is red in colour and is situated on the lower part of the visceral mass just below the pericardium. It is a large sac and bent on itself to form a 'U'-tube, one limb of which receives the oesophagus and the other leads into the *intestine*. The end which receives the oesophagus is called the *posterior* or *cardiac chamber*, while the other end is called the *pyloric chamber*. The cardiac chamber actually constitutes the main part of the stomach. The pyloric chamber exhibits transverse folds at its inner wall, while that of cardiac chamber appears corrugated. A *caecum* or blind pouch opens at the junction of stomach and intestine. The *caecum* does not contain any crystalline style as observed in other gastropods. It is merely a blind diverticulum of the pyloric chamber of the stomach.

HIND GUT: The intestine is long and forms $2\frac{1}{2}$–3 coils. The posterior part of the intestine is nearly straight and turns to the anterior direction and continues as the *rectum*. The rectum lies on the floor of the right side of the mantle cavity and terminates in anus which is situated near the mouth within the right mantle opening.

The digestive glands include the salivary glands and the liver. There are two salivary glands situated one on each side of the oesophagus. The liver or digestive gland is black in colour and constitutes the main bulk of the visceral hump. It gives out two ducts which unite to form a common duct and opens into the stomach.

Locomotion

Pila moves very slowly by creeping on the substratum by its foot. During movement the foot is protruded through the opening of the shell and its flat sole helps in the process. The extension of the foot is caused by sudden influx of blood into the foot. The glands present in the foot produce slimy secretion that helps the animal to glide on dry surface. The foot is provided with vertical, longitudinal and transverse muscles. During locomotion the wave-like contractions on its surface are

produced by the contractions of the vertical muscles. The contraction of the transverse muscles drives the blood forward which causes the extension of the foot in front. During this process the longitudinal muscles contract to pull the posterior end of the foot forward.

Respiratory system

Pila exhibits double mode of respiration, i.e. it can absorb oxygen dissolved in water by ctenidium and can also utilise atmospheric oxygen by the pulmonary sac.

The mantle cavity is incompletely divided into right chamber (branchial) and left chamber (pulmonary) by the presence of epitaenia. Aquatic respiration is performed by the single **ctenidium** situated on the dorso-lateral wall of the right portion of the mantle cavity (Fig. 17.20A). The ctenidium is made up of numerous triangular leaflets or *lamellae*. These lamellae are arranged in single row running parallel to one another along the *ctenidial axis* of the gill. This type of the ctenidium is known as *monopectinate* type. The basal end of each lamella is attached to the pallial epithelium and the other end hangs freely. The branchial lamellae are not of same size. The lamellae are large in the middle of the ctenidium, while the lamellae decrease in size towards the two ends. Each branchial lamella is composed of two layers of epithelia supported by muscle fibres and connective tissue. Two epithelial layers enclose a narrow space. Each epithelial layer consists of three types of cells: (*i*) ciliated columnar cells, (*ii*) non-ciliated columnar cells and (*iii*) few glandular cells. The detailed structures of a gill lamella is shown in Fig. 17.20B. The ctenidium is supplied with blood vessels. In aquatic respiration, a current of water containing oxygen is drawn in by the left siphon into the mantle cavity which ultimately flows into the right side by the help of epitaenia to bathe the ctenidium. The *nuchal lobes* help in the process. After the exchange of gases the water is expelled from the mantle cavity through the right siphon.

The **pulmonary sac** is a closed cavity which hangs from the dorsal wall of the mantle in the pulmonary chamber. The pulmonary sac in Pila is a new attainment in response to its aerial respiration. The pulmonary sac has one opening into the pulmonary chamber which is guarded by two valves. The wall, specially the dorsal wall (Fig. 17.20C) of the pulmonary sac, is

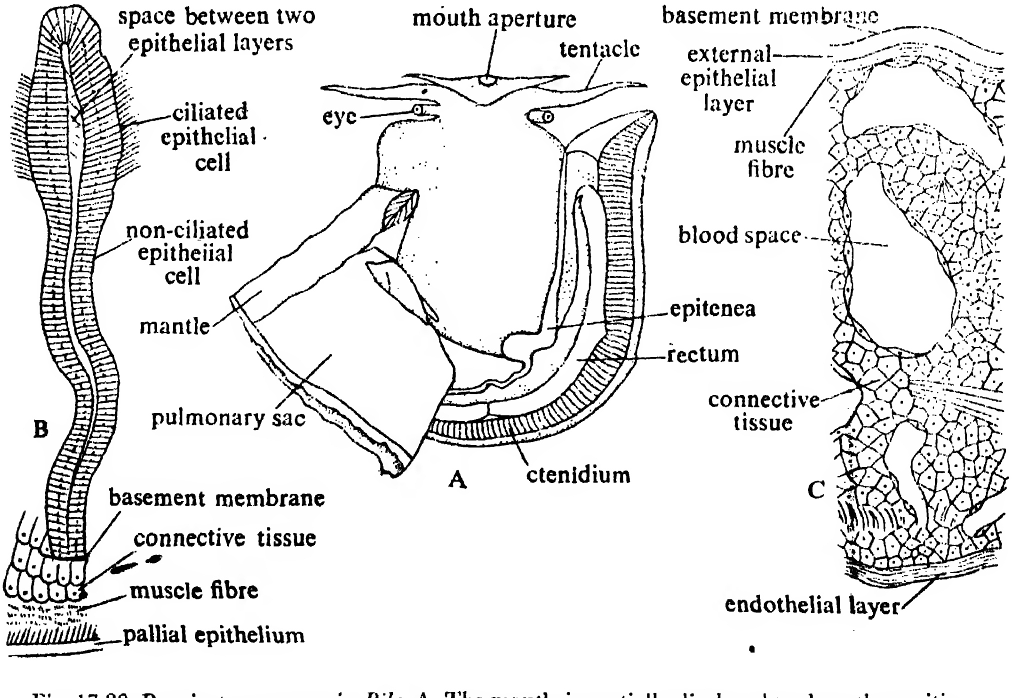


Fig. 17.20. Respiratory organs in *Pila*. A. The mantle is partially displaced to show the position of ctenidium. B. Transverse section of a branchial lamella. C. Diagrammatic sectional view of the outer wall of the pulmonary sac.

highly vascular and helps directly in gaseous exchange. On land, the pulmonary sac becomes filled up with atmospheric air and carries on the process of respiration. Pila can also respire through the pulmonary sac while it remains in water. To inhale atmospheric air, Pila comes to the surface of the water. Before reaching the surface, Pila begins to expand the size of the left nuchal lobe (left siphon). It increases its size both in length and breadth and rolls up to form an elongated respiratory tube. The outer end of the tube extends beyond the level of water and sucks in air from atmosphere. The inner end of the tubes comes in an immediate contact with the opening of the pulmonary sac. The alternate contraction and dilatation of the mantle wall as well as of the pulmonary sac help in the process of respiration. After gaseous exchange the expelled air goes out of the pulmonary chamber by the same route. During this process the branchial chamber remains completely shut off from the pulmonary chamber by the epitaenia which comes in contact with the roof of the mantle.

Circulatory system

The circulatory system of Pila is well-developed owing to aquatic as well as aerial modes of respiration. The heart is situated in the left-hand side of the visceral whorl very near to the posterior end of the ctenidium. The pericardial chamber encloses the heart and the *aortic ampulla*. As the ctenidium lies in front of the heart the animals are included under Prosobranchia. The heart consists of a single auricle and a single ventricle (Fig. 17.21). The auricle is thin-walled and lies in the dorsal part of the pericardium. It communicates with the thick-walled muscular ventricle through the *auriculo-ventricular aperture*. The ventricle is situated just below the auricle in the same axis. The auriculo-ventricular aperture is guarded by semilunar valves which prevent regurgitation of blood from the ventricle to the auricle. The auricle receives oxygenated blood from the ctenidium and pulmonary sac through efferent ctenidial and pulmonary veins respectively.

The lower end of the ventricle gives rise to an aorta. The root of the aorta is provided with two semilunar valves which do not allow the backflow of blood into the ventricle. The aorta immediately bifurcates into two arteries, the anterior one is called *cephalic aorta* supplying blood to the head region and the *posterior* or *visceral aorta* which supplies blood to the posterior part of the body. The cephalic aorta, just after its origin, gives a dilated

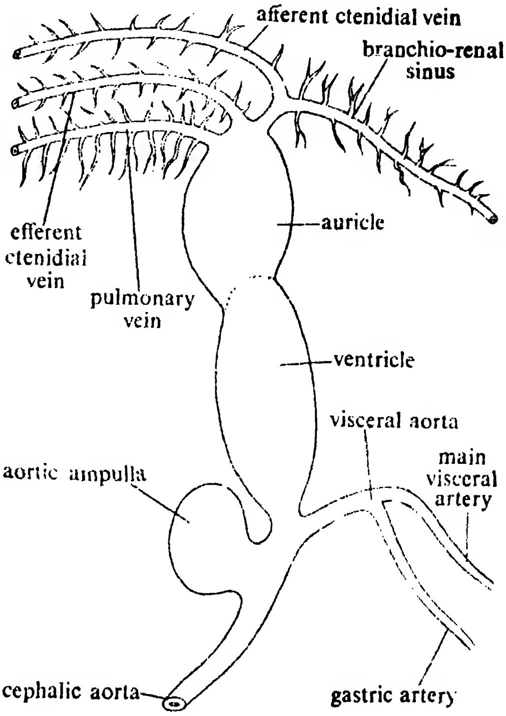


Fig. 17.21. Heart and the main blood vessels in *Pila*.

sac-like outgrowth known as *aortic ampulla*. Both the aortae supply arteries to different parts of the body. The cephalic aorta gives off three arteries along its outer side: (*i*) an artery to the skin, (*ii*) an artery to the oesophagus and (*iii*) an artery to the left part of the mantle, the osphradium and left siphon. The cephalic artery gives off a *pericardial artery* on its inner side. This artery supplies the pericardium and enters into posterior renal chamber. The main trunk of the cephalic artery enters into the *perivisceral sinus* (space surrounding the buccal mass and oesophagus) and then crosses beneath the oesophagus. It then gives off many arteries to the buccal mass, oesophageal wall, right side of the mantle, right siphon and the copulatory organ, eyes, tentacles, etc. (Fig. 17.22). The visceral aorta, immediately after its origin, gives off an artery to supply the pericardium, digestive gland and skin. A little further, the visceral aorta

gives origin to a stout *gastric artery* to the stomach. The main aorta runs along the left margin of the posterior renal chamber and sends branches to the intestine and the posterior renal chamber. It then sends an artery to the digestive gland, the gonad and terminates in the wall of the rectum.

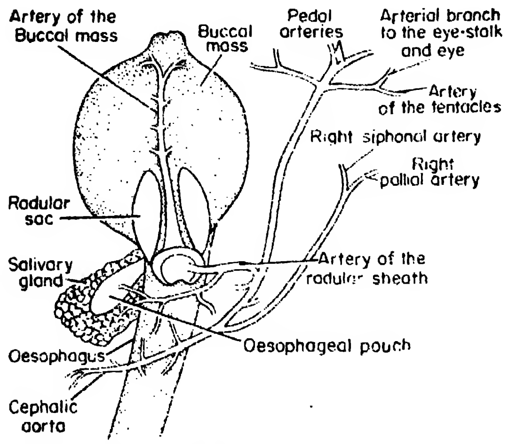


Fig. 17.22. Showing blood supply to the buccal mass and adjoining structures in *Pila*.

The blood, after being distributed to the various parts of the body by the arteries and their tributaries, passes into small spaces (*lacunae*). These lacunae unite to form large *sinuses*. There are four main sinuses: (*i*) *perivisceral sinus*, (*ii*) *peri-intestinal sinus*, (*iii*) *branchio-renal sinus* and (*iv*) *pulmonary sinus*. The *perivisceral sinus* sends blood to the ctenidium and pulmonary sac. The *peri-intestinal sinus* passes blood to the kidney for eliminating metabolic wastes. From the kidney, blood returns to the auricle by efferent renal veins.

Course of circulation of blood. The cephalic and visceral aortae supply blood to the different parts of the body. The cephalic aorta supplies blood to the head, mantle, buccal mass, oesophagus, copulatory organ, columellar muscle and associated structures. The visceral aorta supplies blood to the visceral mass. Although there are four main sinuses, the blood is collected into the perivisceral and peri-intestinal sinuses. From these sinuses, the blood is conveyed either into the pulmonary sac, ctenidium or into the kidney.

During aerial respiration, the blood flows into the pulmonary sac, while in aquatic respiration most of the blood from the perivisceral sinus goes to the ctenidium. After aeration, the blood comes to the auricle by the pulmonary vein or by the efferent ctenidial vein. The blood from the peri-intestinal sinus passes either into the anterior or posterior chamber of the kidney. On its way through the anterior renal chamber, the blood gets rid of nitrogenous wastes and flows either into the ctenidium or into the posterior renal chamber. The posterior renal chamber gets blood either from the peri-intestinal sinus or from the anterior renal chamber. The blood gets rid of its excretory product but without being aerated. Thus mixed blood goes to the auricle for distribution *via* the ventricle. The circulation of blood through the heart and the different parts of the body is shown below:

Efferent ctenidial vein ← Ctenidium
Pulmonary sac ← Perivisceral sinus
↓ ↑
Pulmonary vein Cephalic aorta
↓ ↑
AURICLE → VENTRICLE
↑
Visceral aorta
↓
Peri-intestinal sinus
↓
Efferent renal veins ← Kidney

Excretory system

The excretory organ is the kidney It consists of two renal chambers—one anterior and another posterior (Fig. 17.23)

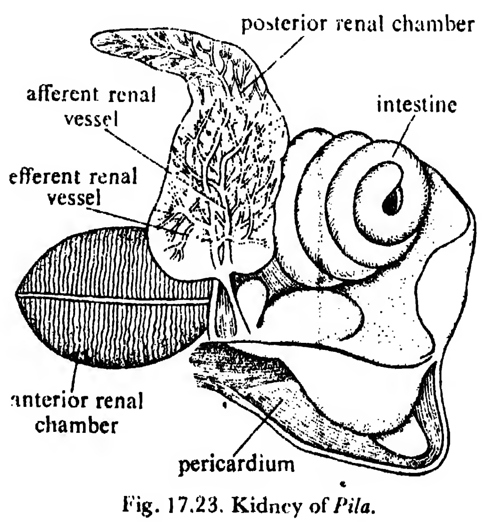


Fig. 17.23. Kidney of *Pila*.

The anterior renal chamber is more or less oval in shape and is situated anterior to the pericardium. It communicates to the posterior renal chamber by one end and the other end opens into the mantle cavity through a slit-like aperture near the epitaenia. It is reddish in colour and its internal cavity presents numerous lamellated processes which reduce the internal cavity. The lamellae are arranged on the floor on either side of the afferent renal sinus and on the roof they are similarly arranged on either side of the efferent renal sinus.

The posterior renal chamber is broad and the colour varies from brownish to gray. It is situated behind the anterior renal chamber. This chamber is separated from the pericardium by a vertical partition (*renopericardial septum*) and opens into it through a slit-like *renopericardial aperture*. The roof has profuse branching of the afferent and efferent renal vessels. The renal chambers are provided with network of blood vessels and take up nitrogenous waste products from the blood. The wastes are discharged into the mantle cavity through the renal duct. From the mantle cavity the waste products are eliminated outside the body.

Nervous system

The nervous system consists of ganglia, commissures, connectives and the nerves to different organs.

Ganglia. The main ganglia are: (1) One pair of roughly triangular *cerebral ganglia* situated on the dorso-lateral sides of the buccal mass, one on each side of the head. (2) One pair of *pleuropedal ganglia* placed below the buccal mass on the lateral side. Each pleuropedal ganglionic mass is more or less rectangular in outline and is formed by the fusion of pleural and pedal ganglia. The *infraintestinal ganglion* is also fused with the right pleuropedal mass. (3) *Visceral ganglion* is very large and appears to be unpaired. It is a bilobed structure and is formed by the fusion of two separate ganglia. The visceral ganglion is placed posteriorly very close to the heart. (4) A pair of *buccal ganglia* are situated on the buccal mass on the two sides of the oesophagus. (5) A single *supraintestinal ganglion* is located near the middle of the left pleurovisceral connectives (Fig. 17.24).

Commissures. The nerve connections between two similar ganglia are generally called the *commissures*. The ganglia are placed on the opposite sides of the body. Two cerebral ganglia are connected by a thick nerve cord called the *cerebral commissure*. The buccal ganglia are also connected by a delicate *buccal commissure*. The inner sides of the pleuropedal ganglia are connected by a broad nerve called the *pedal commissure*.

Connectives. The nerve connections between two dissimilar ganglia are usually called *connectives*. The ganglia may be situated on the same or opposite sides of the body. The cerebral ganglia and the buccal ganglia are connected by *cerebrobuccal connectives*. The pleuropedal ganglia are connected on each side with the cerebral ganglion by *cerebropedal* and *cerebropleural connectives*. That the pleuropedal ganglia are formed by the fusion of separate pleural and pedal ganglia is indicated by the presence of an indistinct constriction and the existence of two separate connectives joining the cerebral ganglia. The pleural ganglion is connected with the visceral ganglion by a *pleurovisceral connective* on each side. The right *pleurovisceral connective* lies below the level of the oesophagus and is generally designated as *infraintestinal visceral connective* and the left pleurovisceral connective is situated above the level of the oesophagus and is termed as *supraintestinal visceral connective*. The supraintestinal ganglion is connected with the right pleuropedal ganglion by an oblique nerve placed above the oesophagus called *supraintestinal nerve*. A very slender nerve called the *infraintestinal nerve* is present connecting the two pleural ganglia of two sides.

Nerves to the different parts of the body. Each cerebral ganglion innervates the eye, the snout and the tentacles on its side. The statocyst is also innervated by a slender nerve arising from the cerebral ganglion. The pedal ganglion gives out numerous nerves to the foot and the pleural ganglion supplies the mantle. The supraintestinal ganglion supplies nerves to the ctenidium and the pulmonary sac. The visceral ganglion sends nerves to kidney, genital organ, pericardium and intestine. The buccal ganglion innervates the buccal mass.

Chiastoneury in Pila. The nervous system of Pila exhibits streptoneurous chiastoneury condition. This is the result of

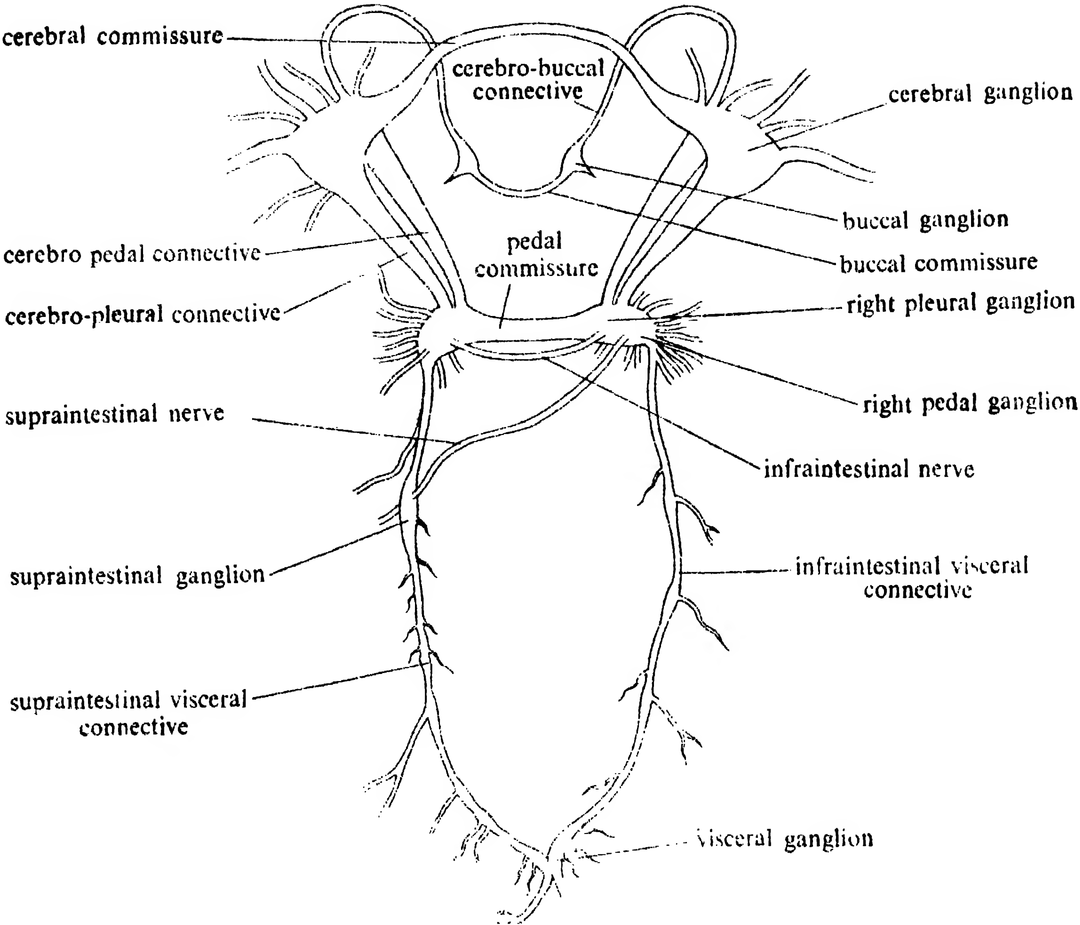


Fig. 17.24. Nervous system of *Pila*.

torsion of visceral mass which has made the whole of the nervous system asymmetrical. The complexities in the nervous system in Pila are due to complete migration of the anal and genital openings to the oral end. The chiastoneury is not so clear in Pila and typical figure-of-8-like arrangement is not produced between the supra- and infraintestinal nerves. No crossing is possible on the right side because of the shifting and fusion of infraintestinal ganglion with the right pleural ganglion. The zygoneury (a secondary connection between pleural and supraintestinal ganglia) is present only on the left side. So the typical chiastoneurous condition with double zygoneury as seen in many gastropods is not clear in Pila.

Sense organs

The sense organs are quite well developed.

Osphradium. The *osphradium* is the organ for taste. It helps to taste the chemical and physical qualities of the incurrent water and also assists in the selection of food. There is only one osphradium which remains suspended from the roof of the pallial cavity on the left side. It is small in size and is roughly oval in shape (Fig. 17.25A). Fig. 17.25B shows the detailed structures of osphradium in sectional view. It has a bipectinate arrangement of its leaflets on the two sides of a central axis. It consists of a single epithelial layer enclosing nervous tissue, connective tissue and blood spaces.

Tentacles. The *labial palps* and the *true tentacles* are the tactile organs.

Statocyst. The statocysts are two in number and are situated one on each side of the pleuropedal ganglionic mass. Each has a round sac-like body (Fig. 17.25C)

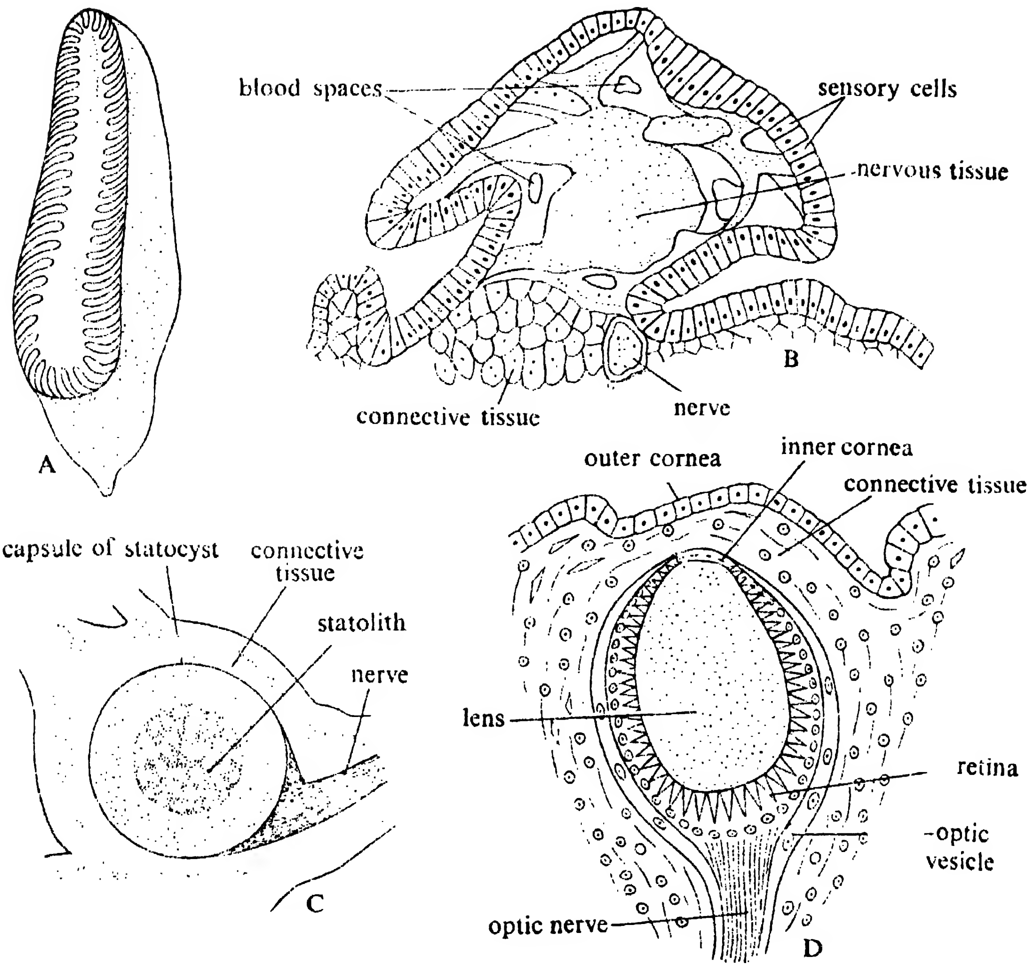


Fig. 17.25. Sense organs in *Pila*. A. An entire osphradium. B. Sectional view of an osphradium. C. A statocyst. D. Sectional view of an eye.

and is kept in position by muscles. The centre of the sac is occupied by a solid mass of calcareous particles known as *statolith*. It is the organ of balance and gets its nerve supply from the cerebral ganglion.

Eyes. Two eyes are located one at the base of each longer pair of tentacles. Each eye has a closed vesicle (Fig. 17.25D) with the inner wall lined by photosensitive or retinal cells. The opening of the vesicle is covered by transparent outer and inner corneas. The cavity between the cornea and the retina is filled up with an oval body constituting the lens. Although, in Pila, the eyes have all the essential components for photoreception, it is very poor in sight.

Reproductive system

The sexes are separate but sexual dimorphism is almost absent.

Male reproductive system. The male reproductive system comprises of *testis* which lies in close contact with the digestive gland and occupies the upper two or three whorls (Fig. 17.26A). The testis is a flat plate-like structure and is more or less triangular in outline. It is cream-coloured. Many fine ducts—the *vasa efferentia*, originating from the testis unite together to open into the *vas deferens*. The vas deferens or male gonoduct is differentiated into (*i*) an upper tubular part; (*ii*) a terminal glandular part and (*iii*) a curved blind tube called *vesicula seminalis* in between the junction of the two parts of the vas

deferens. The *penis* is present in the form of a whip-like flagellum which is partially ensheathed by the *penis sheath* and situated on the right side of the body near the mantle opening. The penis sheath is a simple outgrowth from the inner surface of the mantle. The penis is a long flagellar structure and is capable of great extension. Two types of spermatozoa are encountered in Pila, one is pear-shaped—*Eupyrene* type (Fig. 17.26B) and the other is worm-like *Oligopyrene* type (Fig. 17.26C). The eupyrene types are functional and are capable of fertilizing the eggs.

albumen gland which secretes albumen and the posterior part is distinguished as the *uterus*. At the junction of the tubular and glandular portion of the oviduct there is the *receptaculum seminalis* or the *spermatheca* where spermatozoa remain stored. The terminal part of the uterus is differentiated as *vagina*. The male intromittent organ, the penis, is rudimentary and useless in female. The eggs are fertilized by spermatozoa coming from the spermatheca. Fertilization is internal and oviposition begins a day or two after copulation. The zygote, receives albumen and

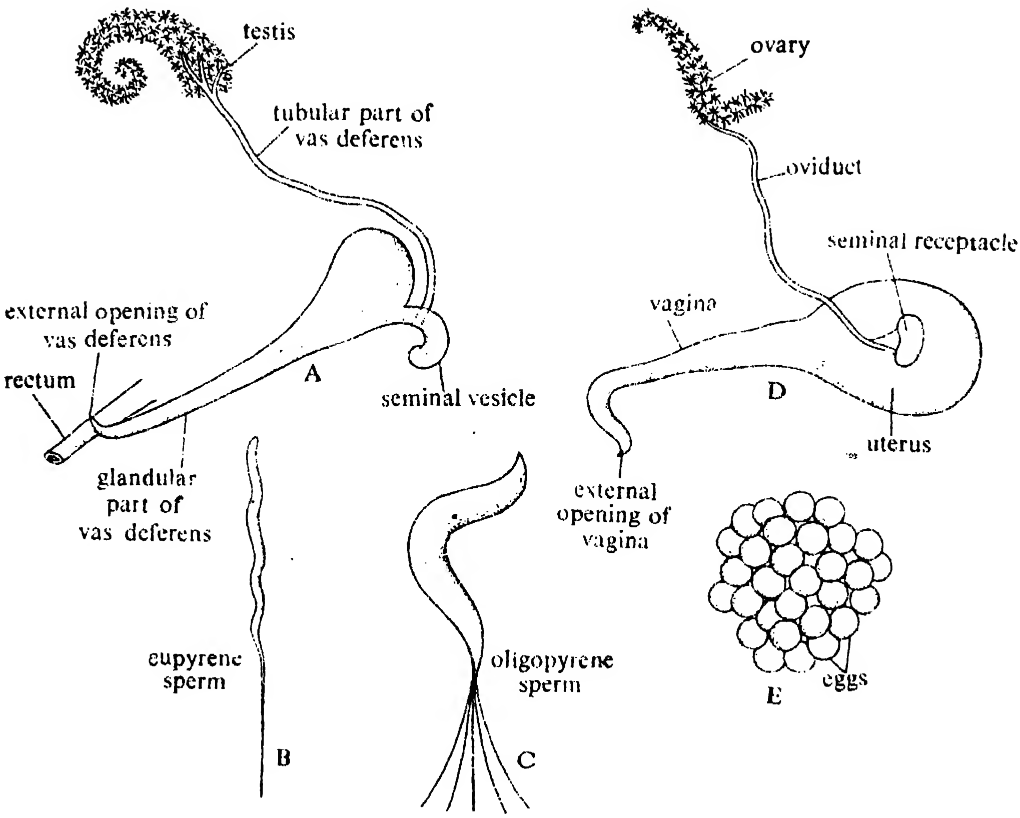


Fig. 17.26. Reproductive systems in *Pila* (after Baini Prashad). A. Male reproductive system. B. Eupyrene sperm. C. Oligopyrene sperm. D. Female genital system. E. Cluster of eggs.

Female reproductive system. The female reproductive system consists of a much branched orange coloured *ovary* situated in the upper whorl of the visceral mass and remains embedded in the digestive gland (Fig. 17.26D). Female gonoduct or the *oviduct* which is differentiated into an upper tubular part comes down along the edge of the liver. The lower glandular part remains on the floor of the mantle cavity parallel to the rectum. The glandular part is distinguishable into a yellow coloured

a coating of shell in the uterus. Few hundred eggs are laid at a time and they adhere together to form a mass (Fig. 17.26E). Existence of rudimentary penis in female is a very remarkable occurrence and is suggestive of the fact that this group had hermaphroditic ancestor.

Development

The development occurs outside the body of the female. The development of

Pila is direct and young snail develops from the fertilized egg. The embryo floats in a central core of liquid albumen which is surrounded by a thick layer of whitish solid albumen. The outer part of the egg consists of a white egg shell and a double layered shell membrane beneath the egg shell.

TABLE 1—MOLLUSCA

COMPARATIVE ACCOUNT OF RESPIRATORY ORGANS IN *UNIO* AND *PILA*

The respiratory system of *Unio* and *Pila* is basically same. Minor variations observed in these two forms are due to adaptation to different modes of life. Unio is exclusively an aquatic animal and the major respiratory organs are the gills or ctenidia. Pila leads double life and lives in water as well as on land. As a consequence, besides gill, a special pulmonary sac or 'lung' is present in Pila for land respiration.

	UNIO	PILA
Modes of respiration	Aquatic.	Both aquatic and terrestrial.
Respiratory organs	Primarily the gills. Highly vascular mantle also acts as an accessory respiratory structure.	Aquatic respiratory organs are mainly the gill and mantle acts as an accessory organ. Terrestrial respiration is done by pulmonary sac or lung.
Number of gill	Two highly developed symmetrical gills are situated one on each side of the body.	Single gill is situated on the right portion of the mantle cavity.
Structure of gill	Complicated structure. Each gill has two plates—external and internal *gill laminae*. Each gill lamina is also a double structure and is formed of outer and inner *gill lamellae*.	Simpler construction. Each gill is composed of numerous triangular *gill lamellae*. These lamellae are arranged in single row parallel to one another along the *gill axis*.
Gill lamellae	There are two gill lamellae in each gill. They are united all along excepting the dorsal side. The space between them is divided into a number of compartments by vertical *interlamellar junctions*. These compartments are called *water tubes*. Between the gill filaments and bounded by *interfilamentar junctions* there are minute apertures (*ostia*) leading into the water tubes.	There are numerous gill lamellae. The basal end of each gill lamella is attached to the pallial epithelium and the other end hangs freely to the mantle cavity.
Structure of gill filament	The gill filaments are extremely elongated structures. Each filament is covered by ciliated epithelium. It is supported by chitinous rods and the cavity is filled with blood.	The gill filaments are lined by ciliated epithelium towards the free end and the basal portion is composed of non-ciliated epithelial cells and few glandular cells.

TABLE 1—MOLLUSCA (contd.)

	UNIO	PILA
Suprabranchial chamber	During respiration water from the water tubes enters into the *suprabranchial chamber* and finally from this chamber water goes out through exhalant siphon.	There is no such structure in Pila. After gaseous exchange the water goes out of the mantle cavity through the right siphon.
Pulmonary sac	Absent, because Unio lives exclusively in aquatic medium.	Pila utilises atmospheric oxygen by a pulmonary sac. It is a closed sac excepting an opening on the roof of the mantle. The dorsal wall of this sac is highly vascular and helps in gaseous exchange.
Nuchal lobes	Absent.	The nuchal lobes form siphons and help in the process of respiration.

TABLE 2—MOLLUSCA

COMPARATIVE ACCOUNT OF NERVOUS SYSTEM OF *UNIO* AND *PILA*

Like other molluscs, the nervous system of *Unio* and *Pila* includes ganglia, commissures, connectives and nerves. The differences observed in them are the result of chiastoneury in Pila.

	UNIO	PILA
Configuration	The nervous system is symmetrically arranged on two sides of the body.	The nervous system assumes asymmetry due to torsion of visceral hump.
Disposition of ganglia	The ganglia are widely separated by long connectives.	The ganglia, particularly at the anterior side, show the tendency towards concentration due to shortening of nerves between the ganglia.
Cerebral ganglia	Two in number. These ganglia are to be called cerebropleural ganglia. Each ganglion is formed by the fusion of cerebral and pleural ganglia of the side. The ganglia are roughly triangular in outline and situated on the antero-dorsal corners of the mouth at the base of labial palps. These ganglia are connected by the cerebral commissure.	Two in number. They are also roughly triangular in outline and are situated on the dorso-lateral side of the buccal mass. The cerebral commissure is very thick.
Pedal ganglia	It is a bilobed ganglionic mass formed by the fusion of two separate pedal ganglia. It is located at the junction of the visceral mass with the foot.	The pedal ganglia have no separate existence. They become fused with the pleural ganglia. On each ventro-lateral side of the buccal mass a large pleuropedal ganglion is present. The pedal and pleural ganglia are separated by an inconspicuous median constriction.

TABLE 2—MOLLUSCA (contd.)

	UNIO	PILA
Pleural ganglia	They have no separate existence and become fused with cerebral ganglia.	They are present and each becomes fused with pedal ganglion of its side to form pleuropedal ganglion.
Visceral ganglia	It is a large bilobed ganglion formed by the fusion of two visceral ganglia. It is situated posteriorly on the ventral side of the posterior adductor muscles.	Like that of Unio it is also a bilobed structure and formed by two visceral ganglia. It is placed posteriorly very close to the heart.
Buccal ganglia	Absent.	Two in number, situated on the dorsal side of the buccal mass on the two sides of the oesophagus. These two ganglia are connected by buccal commissure and are connected with the cerebral by cerebrobuccal connectives.
Intestinal ganglion	Absent.	Only supraintestinal ganglion is present on the left side. Infraintestinal ganglion is fused with the right pleuropedal ganglionic mass. The supraintestinal nerve has the normal position, but the infrainstestinal nerve is present connecting the two pleural ganglia.
Pedal commissure	Absent.	Broad commissure connecting the pleuropedal ganglia is present and situated above the infraintestinal nerve.
Connections between cerebral, pleural and pedal ganglia	A pair of cerebropedal connectives connect the cerebropleural ganglia with the pedal.	Each cerebral ganglion is connected with the pleuropedal ganglionic mass by a pair of thick connectives · cerebropleural and cerebropedal connectives.
Chiastoneury	Absent.	Chiastoneury with Zygoneury is present on the left side. Typical chiastoneurous configuration of the pleurovisceral nerves like the figure '8' is not produced. This unusual chiastoneury is resulted due to gradual migration and fusion of the infraintestinal ganglion with the right pleuropedal ganglionic mass.

EXAMPLE OF THE PHYLUM MOLLUSCA—*ACHATINA*

Achatina (*Lissachatina*) *fulica* is a common giant land snail of India and the Indopacific islands. The anatomical organisation of *Achatina* is more or less similar to that of *Pila* although they belong of different orders of the class Gastropoda. The

anatomical peculiarities in Achatina are due to adaptation to land life.

Distribution

Achatina fulica is a native of Africa. They are found today in some parts of India, Pakistan, Bangladesh and the Indopacific islands. In India, they are abundant in the northern and eastern parts of West Bengal and the Balasore district of Orissa. They are rare in the western districts of the state of West Bengal, Orissa and some districts of Bihar.

Habit and Habitat

Achatina is a terrestrial pulmonate and inhabits open grasslands, gardens and similar habitats. They prefer humid areas. They are mostly nocturnal and spend the daytime under stones, wooden logs and plants. They are found to climb vertical walls and trees up to the height of about 5·8 m. They aestivate during summer to react

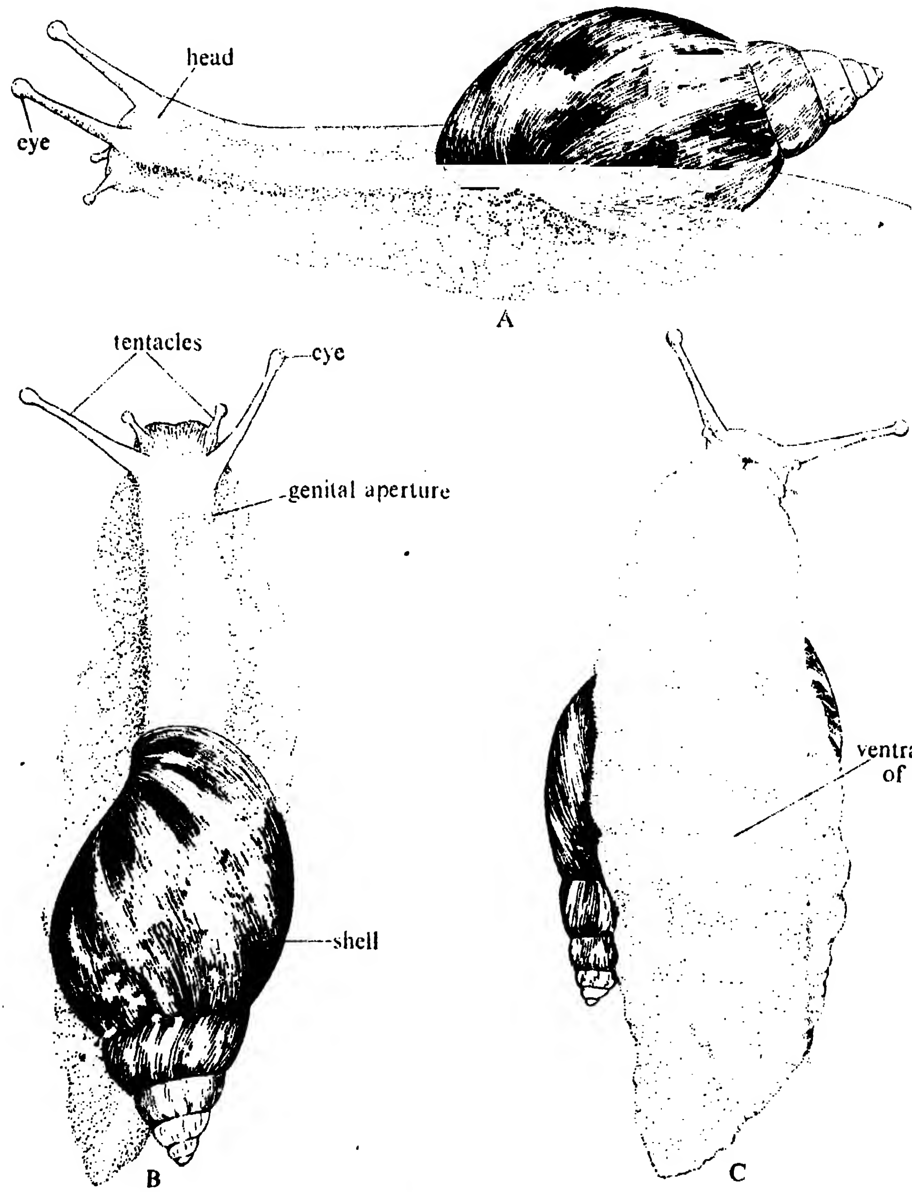


Fig. 17.27. External features of *Achatina*. A. Lateral view. B. Dorsal view. C. Ventral view.

inpending desiccation. They exhibit divergent food habits. They are herbivorous and eat the vegetation available in the area. The presence of well-developed two-lobed crop in Achatina is an adaptation to devour maximum quantity of food and to store them for future use. Although Achatina is primarily a herbivorous mollusc, it equally prefers to take dead insects and snails. It has been reported by Ghose (1963) that Achatina takes pieces of meat in laboratory.

External structures

The shell covering the body is elongated and the operculum is absent. The shell is of light horny colour. The columella and whorl of the shell is whitish in adults. The head is comparatively long (Fig. 17.27A) and can be projected to a great extent (Fig. 17.27B). Eyes are two in number and are placed at the tip of the longer tentacles. The longer tentacles are designated as the *ocular tentacles* which can regenerate fully with all their component parts. Besides these long tentacles, there are a pair of small *ventral tentacles* in the snout. Genital aperture is located on the right side posterior to head. The foot is flat and is modified for creeping by the large ventral sole (Fig. 17.27C). The foot is provided with a large tubular slime gland which produces profuse quantity of slime. The mantle cavity is closed excepting the right-hand side near the pulmonary aperture. Removal of mantle shows the disposition of the internal organs (Fig. 17.28).

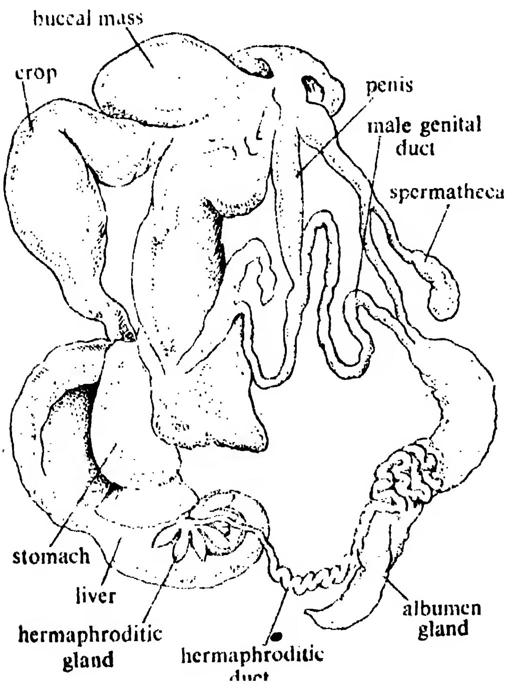


Fig. 17.28. Dissection of *Achatina* showing the internal organs.

Coelom

In *Achatina*, the internal spaces are haemocoelic. The true coelom is restricted within the pericardial cavity and the cavity around the gonad.

Digestive system

The digestive system in *Achatina* is remarkably simple. This simplicity is correlated to terrestrial life. The digestive system consists of alimentary canal and digestive glands. The alimentary canal comprises of buccal mass, oesophagus, crop, stomach, intestine and rectum. The digestive glands are the salivary and digestive glands (Fig. 17.29).

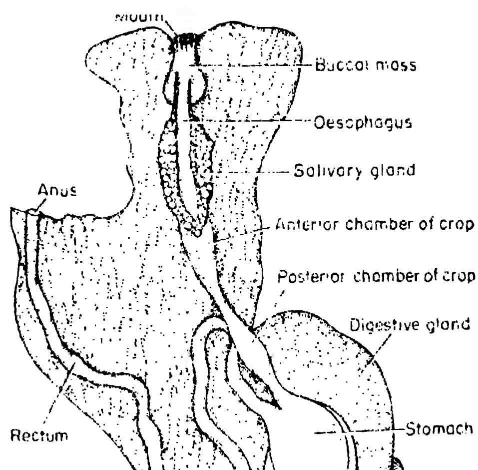


Fig. 17.29. Digestive system of *Achatina* (after Ghose).

MOUTH: It is a semicircular opening placed ventrally to the anterior part of the snout. It encloses a small cavity (*vestibule*) posteriorly. The labial palps are placed dorsal to the corners of the mouth.

BUCCAL MASS: The anterior part of the alimentary canal becomes modified into the buccal mass. The buccal mass is thick-walled and muscular. It is broader at the

posterior end and narrower anteriorly. The buccal mass can be protracted and retracted by sets of protractor and retractor muscles respectively. The buccal mass has a complicated structural construction. The mouth opens into the buccal cavity and is guarded dorsally by semicircular jaw on the dorsal surface. The jaw is composed of a homogeneous cartilage. The jaw is operated by powerful sphincter muscle. The ventral surface of buccal mass is formed by the sphincter muscle. The radula is present on the floor of the buccal cavity. It is a ribbon-like structure with a blunt posterior end and a narrow anterior end. It contains 140 rows of teeth, each row having 129 teeth. The radula is operated by well-developed extrinsic muscles. The forward movement of the radula is caused by the anterior and antero-ventral radular protractor muscles. The backward pull is effected by the radular retractor muscles. The radular sac starts from the postero-ventral side of the buccal cavity while the oesophagus and the salivary glands run from the dorsal surface. The radular sac contains a central rod called *collostyle*. This rod is oval in shape and small in size. It is composed of white dense connective tissue elements. The buccal cavity is lined with a thin cuticular layer. The cavity is divisible into two chambers. The anterior chamber is tubular and the posterior chamber is dorsally compressed and arched. The peculiar configuration of the posterior chamber is due to the presence of an odontophore. The main body of the odontophore is formed by the buccal cartilage. It is horseshoe-shaped and supports the radula.

Oesophagus: The buccal cavity leads into a narrow thick-walled tube called oesophagus. The inner wall is ciliated and bears longitudinal folds and is covered externally by flattened epithelium. The oesophageal glands are present in the wall.

Crop: The crop is a spacious thin-walled sac. The junction of the oesophagus and crop is marked by the large lumen of the latter. The crop is divided into an anterior and a posterior chamber. A constriction is present between the two chambers which acts as sphincter and regulates the passage of food materials. The posterior chamber opens into the stomach by a round aperture. A short and wide duct from the digestive gland opens into the posterior chamber. Histological picture of the crop shows the presence of the following layers:

(*i*) Innermost layer—composed of columnar epithelium. Often ciliated and interspersed goblet cells are present.

(*ii*) The outermost layer consists of muscles which are differentiated into an outer circular muscle layer and an inner longitudinal muscle layer.

Stomach: The crop opens into the *stomach* which remains embedded in the digestive gland. The stomach is a thick-walled heart-shaped structure. The crop, stomach and intestine form an 'U'-like configuration. The base is formed by the stomach and the limbs are formed by the crop and intestine. The wall of the stomach is muscular. The epithelium is ciliated with numerous gastric glands. A digestive duct opens into the posterior part of the stomach.

Intestine: The intestine is an elongated coiled tube. It ends in the rectum. The wall is thin with patches of longitudinal fibres and intestinal glands.

Rectum: The rectum is a straight tube. It runs along the posterior wall of the mantle cavity and terminates in anus. The anal region of the rectum bears strong muscular folds which serve as sphincter. The wall is thin and the longitudinal and circular muscles are present. The epithelium is ciliated with rectal glands.

Two salivary glands and one digestive gland are associated with the alimentary canal.

Salivary glands: The salivary glands are elongated paired structures. These glands are cream-white in colour. They are united posteriorly but are free anteriorly. The salivary ducts open into the buccal cavity. These glands are many lobed structures and each lobe is composed of *mucous* and *serous alveoli*. The secretion of the salivary glands is poured into the buccal cavity.

Digestive gland: The digestive gland is a large spirally twisted gland. It is bilobed and divided into an anterior lobe and a posterior lobe. The duct from the anterior lobe opens into the crop while the duct from the posterior lobe opens into the stomach. The digestive gland is composed

of numerous lobules. Each lobule is composed of four types of cells. *Storage, calciferous, vesicular* and *pseudopodial cells* are claimed to be present. All the cells excepting the calciferous cells are digestive in function and they are of columnar type. The calciferous or lime cells are roughly triangular in shape with granules of calcium phosphate.

Locomotion

Achatina moves by the foot. The foot is very much elongated and has a flat ventral sole. The secretion of the slime gland and the musculature of the foot help in progression. It moves on the substratum by producing waves of contraction passing from the posterior to the anterior end along the sole. The sole is lifted from the substratum at the sites of contraction waves and proceeds forward as the areas between the waves again restore contact with the surface. By such alternate process of lifting from surface and making contact with the substratum Achatina moves very slowly from one place to another.

Respiratory system

Achatina is exclusively terrestrial and respires by the mantle cavity which transforms into pulmonary sac or the so-called lung. The wall of the mantle cavity is highly vascular.

Circulatory system

The heart of Achatina is composed of one *auricle* and one *ventricle* (Fig. 17.30A).

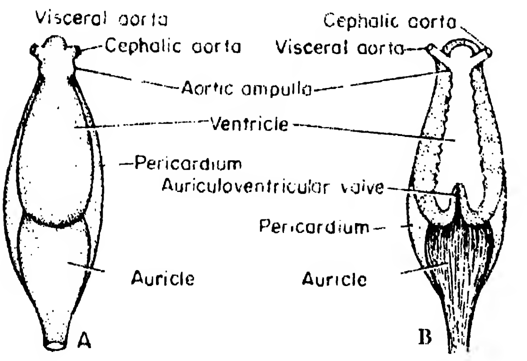


Fig. 17.30. Structure of heart of *Achatina*. A. Intact heart. B. Longitudinal sectional view (after Ghose).

The heart is enclosed by *pericardium*. The pericardial chamber is situated on the left side of the mantle and lies parallel to the kidney. The pericardial chamber has an elongated oval appearance. The pericardium is a closed sac except for the renopericardial opening. The pericardial chamber is narrower towards the ventricular end and broader at the auricular end. The pericardium is fused with the apex of the ventricle near the base of the aortic ampulla. The auricle is also fused with the pericardium. The pericardium is a tough membrane consisting of interwoven muscle fibres.

The auricle is a thin-walled wine-glass-shaped chamber. The narrow auricular apex is continued with the pulmonary vein. The wall is provided with longitudinal, transverse and oblique-branched muscle strands. These strands form a coarse meshwork and reduce the cavity of the auricle (Fig. 17.30B). The ventricle is a conical chamber with a narrow apex and a broad base. The wall of the ventricle is thick and spongy. The muscle fibres form prominent ridges on the inner side of the ventricle. The myocardium is made up of non-striated, ramified and syncitial muscle fibres. The auricle communicates with the ventricle by the auriculo-ventricular aperture. This aperture is guarded by two semilunar valves. The ventricle gives off an inconspicuous aortic *ampulla*. The walls of the ventriculo-ampullar and pulmo-auricular apertures are provided with concentric sphincter muscles which act like valves. The aortic ampulla is formed by the bases of the aortae. Two arteries, viz. a *cephalic artery* and a *visceral artery* arise from the apex of the ampulla. These arteries supply blood to the different parts of the body. The blood from the different parts of the body is collected in sinuses and from these sinuses blood returns to auricle by veins.

Excretory system

The excretory system consists of kidney. Originating from the anterior end of the kidney, the ureter runs along a groove to the posterior end. The kidney is a single-lobed body adherent to the mantle. It is a spongy, elongated organ of dull grayish colour. It is situated at the postero-lateral part of the mantle cavity and lies parallel to the heart. The kidney has a peculiar configuration (Fig. 17.31). It has a narrow and rounded anterior end while the posterior part is broader and crescent-shaped. The kidney is made up of numerous

narrow folds enclosing an inconspicuous central lumen. The ureter is divided into two portions—the *adrenal ureter* and the *adrectal ureter*. The adrectal ureter

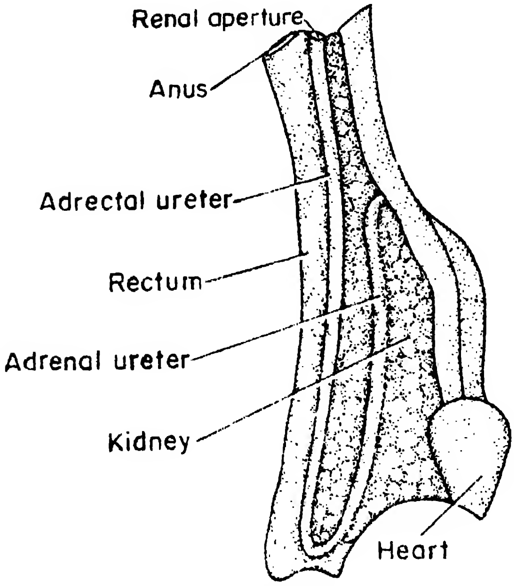


Fig. 17.31 Kidney of *Achatina* (after Ghose).

proceeds anteriorly in close contact with the rectum while the adrenal ureter runs by the postero-lateral side of the kidney. The adrectal ureter opens to the exterior by the *renal aperture* located close to the anus.

The kidney is bounded by a thin capsule. This capsule is fused with the ventricular end of the pericardial chamber leaving a small rounded *renopericardial aperture*. This aperture leads into a short and ciliated slender passage. The passage becomes extensively branched to open into the cavity of the kidney. The kidney gets blood supply from the *renointestinal artery* of the cephalic aorta. The urine is stored in the lumen and the ureter. The urine also helps to keep the surface of the mantle moist. Normally the rate of discharge of urine is slow but during aestivation this rate is slightly higher. Uric acid excretion increases during aestivation in Achatina.

Nervous system

The nervous system of Achatina consists of cerebral, pleural, parietal, visceral, pedal and buccal ganglia. The parietal, pleural, visceral and pedal ganglia form a ring. The cerebral, pleural, pedal and visceral ganglia are concentrated in the head region due to shortening of the nerves between them. All these ganglia are paired excepting the visceral which is unpaired and shows the tendency towards fusion with the pleural. The pleural and pedal ganglia are separate and are connected with the cerebral ganglia by connectives. All these ganglia are located around the oesophagus and thus form a *circumenteric nerve ring*. The circumenteric nerve ring on the ventral side of the oesophagus forms a visceral nerve chain. Based on the disposition of ganglia on the visceral nerve chain the nervous system is designated as the *Zonitoid* type. This chain has five ganglia—one visceral, two parietals and two pedals, but they are very closely set. The cerebral ganglia are rounded bodies situated dorsal to the oesophagus and behind the buccal mass. From each ganglion several nerves, viz. *ocular nerve*, *ommatophoral nerve*, *superior frontal nerve*, *inferior frontal nerve*, *posterior oesophageal nerve*, *cerebrobuccal connective*, *nuchal nerves* and *labiotentacular nerve* originate to supply the head and the anterior region of the visceral stalk (Fig. 17.32). The buccal ganglia are paired and connected by a narrow transverse commissure. The buccal ganglia supply nerves to the buccal mass. The pleural ganglia supply nerves to the middle portion of the visceral stalk while the parietal and the visceral ganglia supply nerves to the base of the visceral stalk. The pedal ganglia are massive and give off nine pairs of nerves to the foot. The nervous system becomes condensed due to reduction of all commissures and connectives between the different ganglia and consequent fusion and approximation of ganglia. Untwisting and gradual shorting of the visceral chain have caused the cephalic concentration of the ganglia. Distinct chiastoneury is not observed in Achatina. The pallio-parietal nerve arising from the left side of the visceral ganglion turns to the right and proceeds along the right medio-parietal nerve. This complication is due to head-foot torsion.

Sense organs

Achatina is provided with well-developed sense organs. The sense organs are:

(*a*) Eyes: Two eyes, one at the tip of each large tentacle (ocular tentacle) are present. Each eye appears as small black

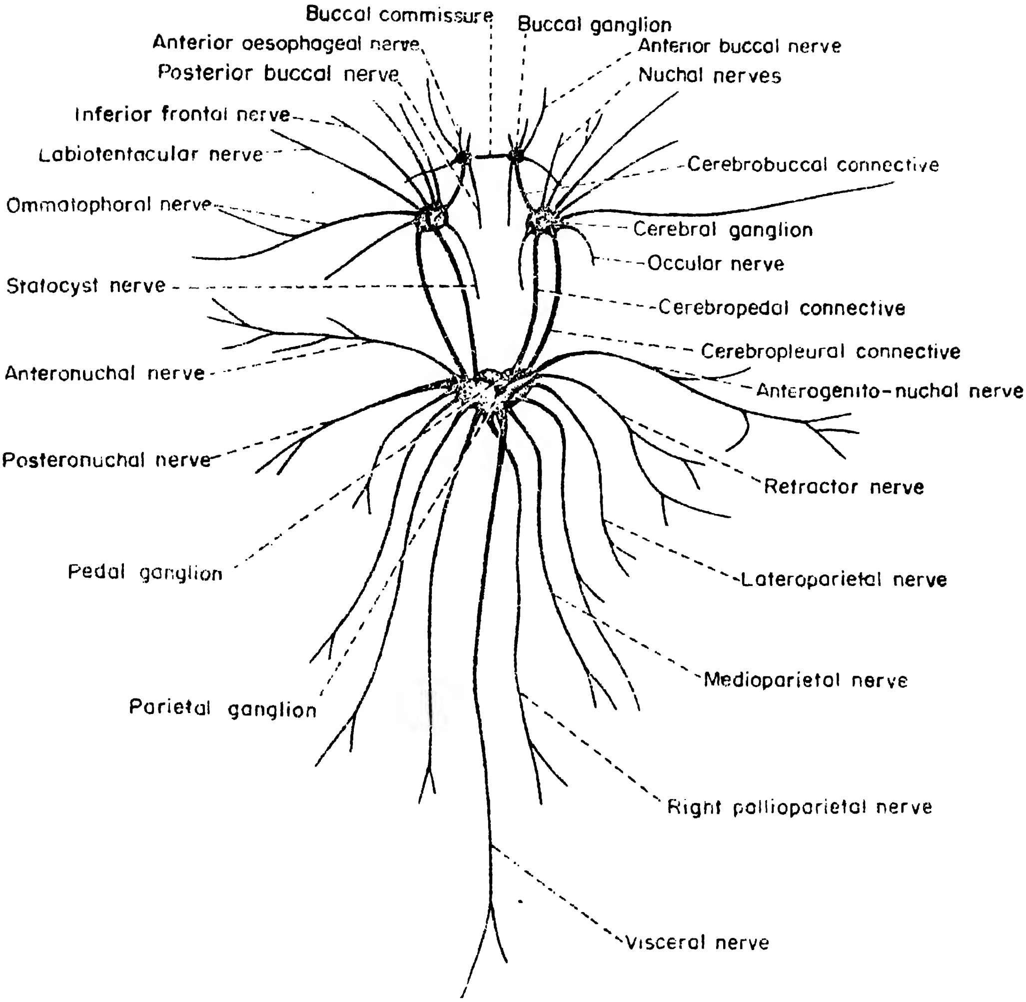


Fig. 17.32. Nervous system of *Achatina*. The cerebral ganglia are actually placed very closely. For convenience and easy understanding they have been set apart (after Ghose).

dot and consists of an outer cornea, an inner cornea, a structureless lens and a retina.

(*b*) Olfactory organs: Four olfactory organs, two at each tentacle, are present. An olfactory organ consists of a club-shaped olfactory ganglion.

(*c*) Statocysts: Two statocysts are the organs for balance. A statocyst is placed on the dorso-lateral side of the pedal ganglion. The statocysts are spherical sac-like structures lined by fibrous tissue. The cavity is filled with elliptical statoconia.

(*d*) Tactile organs: The ventral tentacles, foot and snout act as tactile organs.

Reproductive system

Achatina is a hermaphroditic animal. The reproductive system consists of the following structures: (*a*) an ovotestis (hermaphroditic gland), (*b*) an ovotestis duct, (*c*) a spermoviduct with prostatic acini, (*d*) a vas deferens with penis, (*e*) an oviduct with vagina and (*f*) a genital atrium opening to the exterior through the genital aperture (Fig. 17.33).

Ovotestis: The ovotestis is a multilobate body embedded in the posterior lobe of the digestive gland. There are four or five finger-like lobes in the ovotestis. Each lobe has many lobules. Most of such lobules produce sperm cells while a few produce both ova and sperm cells.

Ovotestis duct: Each lobe of the ovotestis produces a duct and these ducts of the lobes unite together to form a single ovotestis duct. This duct opens into the spermoviduct. The ovotestis duct is

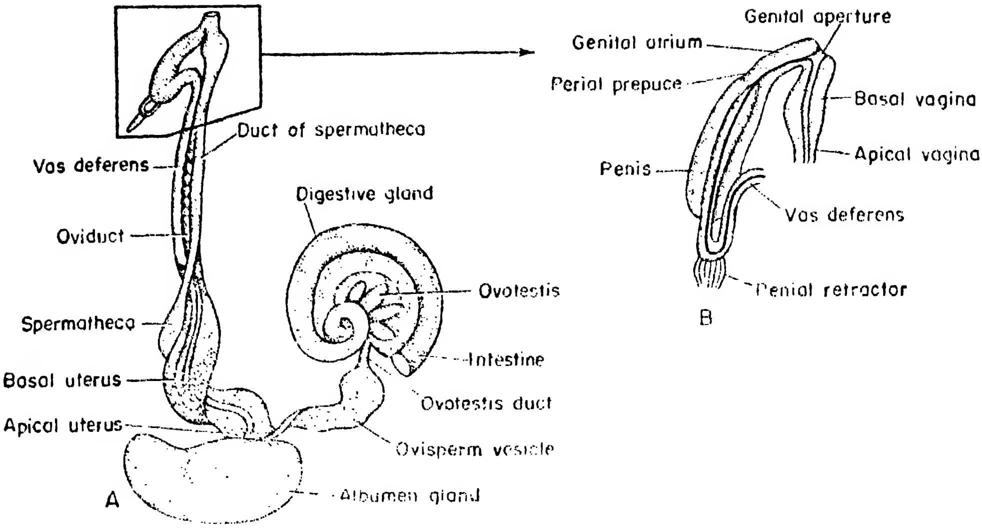


Fig. 17.33. Reproductive system of *Achatina*. A. Entire system. B. Enlarged terminal portion

divisible into three parts: (*i*) The first or the *apical ovotestis duct* is a narrow straight tube which opens into (*ii*) the *ovisperm vesicle* where the sperms remain stored. It is much folded and held together by a thin layer of connective tissue. The third part or (*iii*) *basal ovotestis duct* is a narrow and twisted duct.

Albumen gland: The basal ovotestis duct is placed against the concave face of the albumen gland and enters into it. The albumen gland is a cream-white gland which enlarges during breeding season. It is composed of many vesicles and enclosed by a capsule. The vesicles open into a ciliated albumen canal which leaves it as a short albumen duct.

Spermoviduct: The ovotestis duct opens into the spermoviduct which receives secretion from the prostatic acini. Each prostatic acinus is composed of many alveoli which open into a central prostatic canal.

Uterus: The uterus is divided into an apical and a basal part. The walls of the apical and basal uteri are much folded. The basal uterus opens into a tubular oviduct. The spermathecal duct opens into the anterior part of the tubular oviduct. The tubular oviduct ends in the vagina. The vagina is divisible into a tubular apical part and an anterior expanded basal part. The basal part opens into the *genital atrium*.

Vas deferens: The vas deferens remains in continuation with the *sperm groove* or *sulcus*. The sulcus is a narrow incomplete passage running along the inner concave edge of the spermoviduct. The sulcus is separated from the uterus by two folds of the wall of the spermoviduct. The vas deferens, on reaching the posterior end of the *basal vagina*, turns left and enters the *penis*. The penis is a curved muscular organ which continues anteriorly as the *penial prepuce* to open into the genital atrium. The genital atrium opens to the exterior through the common *genital aperture*. The common genital aperture, as stated earlier, is situated on the right side and posterior to the head.

Development

The fertilized egg of Achatina divides into a number of cells by total and spiral cleavages. The first two cleavages are equal. The subsequent cleavages are unequal. The blastula is a coeloblastula and embolic type of gastrulation occurs. After passing through developmental stages, the embryo transforms into a modified veliger stage. Gastrulation is completed by 36 hours and the embryo grows rapidly to assume an elongated configuration. Subsequently the blastopore is shifted dorsally and the ventral lip elongates to form the foot-rudiment. The visceral hump begins to differentiate antero-dorsally to the blastopore. The prototroch becomes distinct which develops cilia to transform into the velum. The embryo at about 48

hours stage resembles a veliger larva. The development of Achatina beyond the veliger stage occurs in subsequent stages. The whole process is completed by 15 days.

EXAMPLE OF THE PHYLUM MOLLUSCA— *NEOPILINA*

Neopilina galatheae is a living representative of the class Monoplacophora. This newly discovered species possesses peculiar admixture of molluscan and annelidan features. Neopilina is a very primitive member amongst the molluscs and represents a sort of connecting bridge between the annelids and molluscs. There are many fossil relatives of this genus which were quite abundant in Cambrian to Devonian strata. The genus, *Neopilina*, was collected from the western coast of Maxico. This discovery has added new dimension as regards the phylogenetic relationship of the molluscs as a whole with the annelids. The Danish Zoologist, Lemche first collected the species in 1952 from the assorted molluscs collected in Galathea expedition. Another species was discovered during the voyage of American Research vessel, Vema in 1958. The anatomy of *Neopilina galatheae* was exhaustively worked out by Lemche and Wingstrand (1959).

Habit and Habitat

Neopilina is a deep-sea variety and was collected from the Pacific Ocean at depths from 2500 to 5000 m. Neopilina lives in mud and feeds mainly on foraminifera. It also takes radiolarians and diatoms as evidenced by their remains in its stomach.

External structures

The body of Neopilina is more or less bilaterally symmetrical and exhibits metameric segmentations like annelids. *Neopilina galatheae* is about 3·7 cm long, 3·3 cm wide and 1·4 cm high. The dorsal side of the body is covered by a thin *shell*. The shell is circular in outline. The apex of the shell is drawn anteriorly and is slightly bent (Fig. 17.34A). The shell is composed of a *prismatic* and a *nacreous* layer, covered over by *periostracum*. These three layers of the shell are formed from the margin of the mantle. The soft parts of the body are seen only from the ventral side. There is a large flat *foot* like that of Chiton. Surrounding the foot and head there is a deep *pallial groove* containing five pairs of *gills*. The *mouth* is situated medially in front of the foot and the *anus* is located posterior to the foot (Fig. 17.34B). In front of the mouth there is a *transverse labial swelling* which prolongs laterally into two ciliated lobes, one on each side. These ciliated lobes are comparable to the anterior *labial palps* of *Unio*. Anterior to the transverse swelling there is a pair of small *preoral tentacles*. There is a swollen *labium* which bears a number of *postoral tentacles* on the anterior surface. There are eight pairs of *dorso-ventral muscles* in Neopilina (Fig. 17.35A). These muscles originate from the shell and extend to the median wall of the pallial groove. The dorso-ventral muscles correspond to the columellar muscles of the gastropods.

Coelom

The coelom is represented by a caudal pericardium and two pairs of spacious gonocoels.

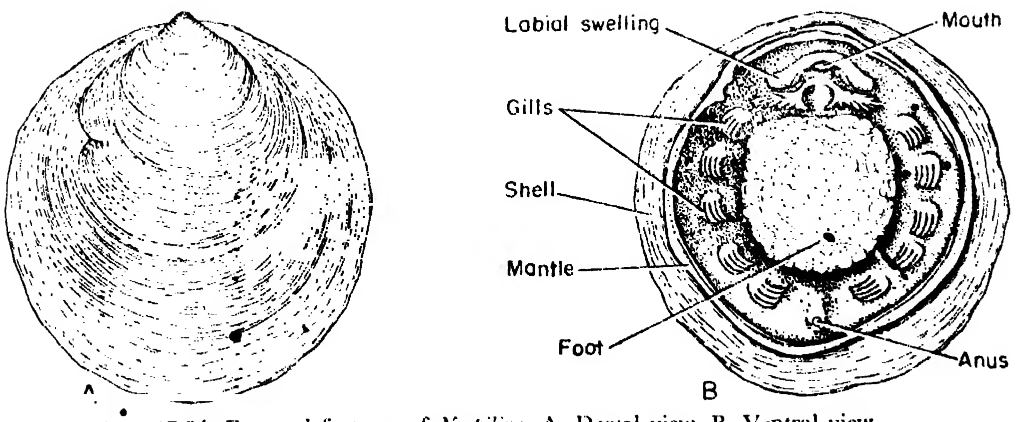


Fig. 17.34. External features of *Neopilina*. A. Dorsal view. B. Ventral view.

Digestive system

The mouth leads into the *buccal cavity* which is covered by a cuticular plate. The pharynx extends to the dorsal side and bears a radular sac with a *radula*. The pharynx produces a pair of long, thin-walled diverticula called the *foregut gland*. The stomach contains a *crystalline style* in its median diverticulum. The stomach bears a pair of large folded *midgut glands*. The stomach continues as a coiled *midgut* (Fig. 17.35B) to end in the *anus*.

body and is collected in different sinuses like other molluscs.

Excretory system

The excretory organs are six pairs of *nephridia*. The nephridia are designated as the *metanephridia* which lie at the bottom of the pallial groove. A metanephridium has the appearance of a folded sac which opens to the exterior by *nephropore* near the gill. The metanephridia are modified coelomoducts.

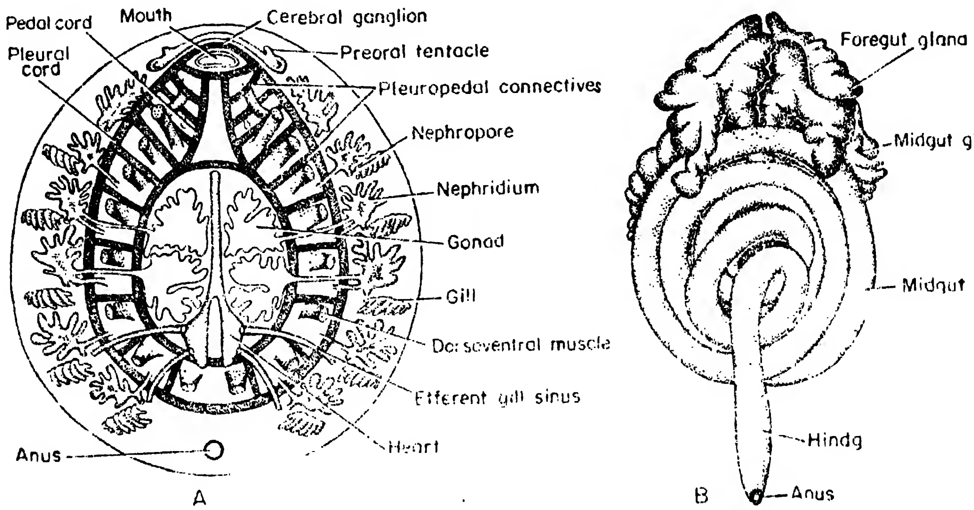


Fig. 17.35. Internal organisation (A) and digestive system (B) of *Neopilina*.

Locomotion

There is a large flat ventral foot which occupies almost whole of the ventral side of the body. It is modified for creeping movement.

Respiratory system

The respiratory organs of *Neopilina* are the gills attached to the dorsal side of the pallial groove. There are five pairs of gills in *Neopilina galatheae* while in *Neopilina ewingi* there are six pairs. The posterior gills have lamellae usually on one side, while the anterior ones have lamellae on both sides. The gills are supplied with blood by the afferent gill sinus to be returned by efferent gill sinus (Fig. 17.36).

Circulatory system

The heart consists of two pairs of auricles and two ventricles. The ventricles are located on the lateral side of the hindgut and continue as a single aorta. The aorta supplies blood to the different parts of the

Nervous system and Sense organs

The nervous system is primitively built and corresponds to the ladder-like arrangement of Chiton. Two ill-developed *cerebral ganglia*, one on each side of the pharynx are present. The cerebral ganglia are connected by *cerebral commissure* which encircles the mouth. The cerebral ganglion and its commissure innervate the preoral tentacles, labrum, oral lobes and subradular organ. The pedal cords innervate the foot. The pleural cords send nerves to the mantle, gills and nephropores. The sense organs of Neopilina include a pair of *statocysts*, a *subradular organ* and *preoral* tentacles. The pedal and pleural cords are connected posteriorly to form loops with many cross-connections between them. Such an arrangement in the nervous system speaks of primitive organisation.

Reproductive system

Neopilina is a dioecious animal. The gonads are paired ventral organs (Fig.

17.36) which open into the third and fourth metanephridia. These metanephridia act as the gonoducts. The sperms and ova are discharged through nephropores. Accessory reproductive glands are lacking.

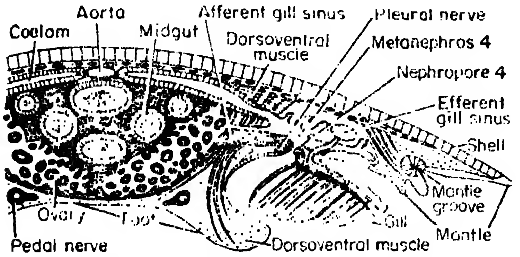


Fig. 17.36. Diagrammatic transverse sectional view of *Neopilina*.

Relationships of Neopilina with other Molluscs

Neopilina possesses many peculiar features which make the precise relationship of it debatable. The metameric arrangement of dorso-ventral muscles, gills, nephridia and gonads establish its phylogenetic relationship with the annelids. As regards its intraphylar position, it shows many similarities with *Chiton*, *Nautilus* and many gastropods. The location of the body in the shell corresponds closely to that of *Nautilus*. Features common in Neopilina and Chiton are the shape of body, the flat ventral foot, the shell covering the head and mantle, many dorso-ventral muscles, auricles, numerous gills, etc. But Neopilina differs from Chiton by having a single shell, statocysts and the nephropores functioning as the gonoducts. It is claimed that the gastropods have evolved from Neopilina *via* Nautilus-like form which has a symmetrical shell. In gastropods, torsion of the visceral mass has resulted the asymmetrical configuration, reduction of dorso-ventral muscles into a single columellar muscle, reduction in the number of gills and metanephridia and many other features.

Example of the Phylum Mollusca—*SEPIA*

Sepia is a typical representative of the class Cephalopoda. Members of this class show highly specialised and complex structural organisation amongst the molluscs. Description of Sepia will give a general idea about the cephalopod organisation. Sepia is popularly known as cuttle fish.

Habit and Habitat

Sepia is exclusively marine and usually remains near the surface of water. They are good swimmers. They usually swim at night and rest flat on bottom during daytime. The lateral fins, funnel and the arms help in swimming. Their flattened bodies indicate their sand and mud-dwelling habit. They can make burrow by using the funnel and use fins as shovel to cover the body with sand. They usually move in groups (Gregarious). They are carnivorous and live on small fishes, crustaceans and other small animals.

External structures

The body is divided into a distinct head and an elongated dorso-ventrally flattened

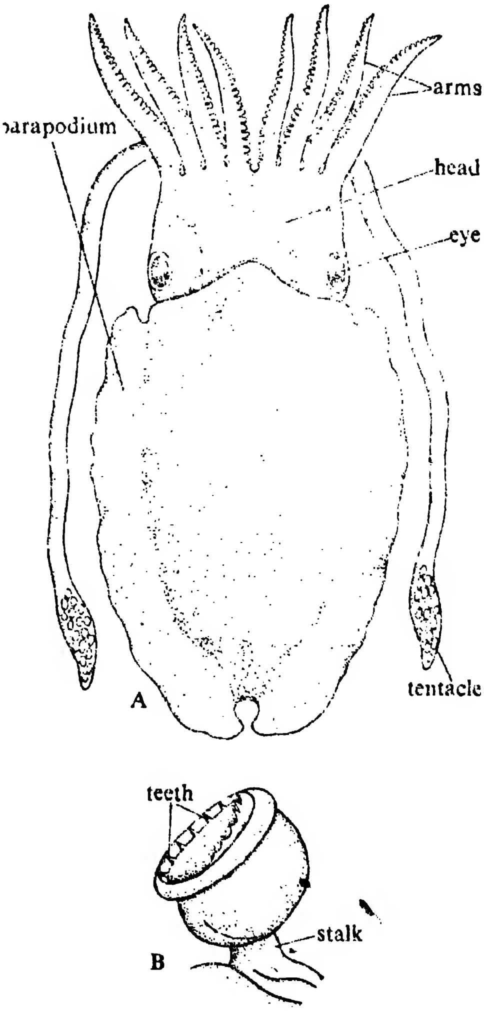


Fig. 17.37. A. Dorsal view of *Sepia*. B. Structure of a sucker in *Sepia*.

trunk. A narrow neck connects the head with the trunk. The head bears two well-formed eyes and ten oral arms. The mouth is surrounded by the bases of the ten long oral arms (Fig. 17.37A). Excepting the fourth pair, all the oral arms have convex outer and flat inner surfaces. The inner surface possesses four longitudinal rows of suckers which help to grasp the prey or foreign bodies. The fourth pair of the arms are comparatively longer and are called the tentacles. The tentacles have suckers restricted to the thickened tips. Each sucker is a muscular cup-like body. The rim of the sucker has small horny teeth and the whole sucker rests on a short stalk (Fig. 17.37B). During breeding season the fifth arm on the left side (only in males), becomes modified into a *hectocotylized arm* which helps in copulation and such a change is known as *hectocotylization*. The oral arms are modified foot and are innervated by pedal ganglion.

The trunk is covered by a thick mantle. Communicating with the mantle cavity a large tube known as funnel is present on the mid-ventral side of the oral end. The

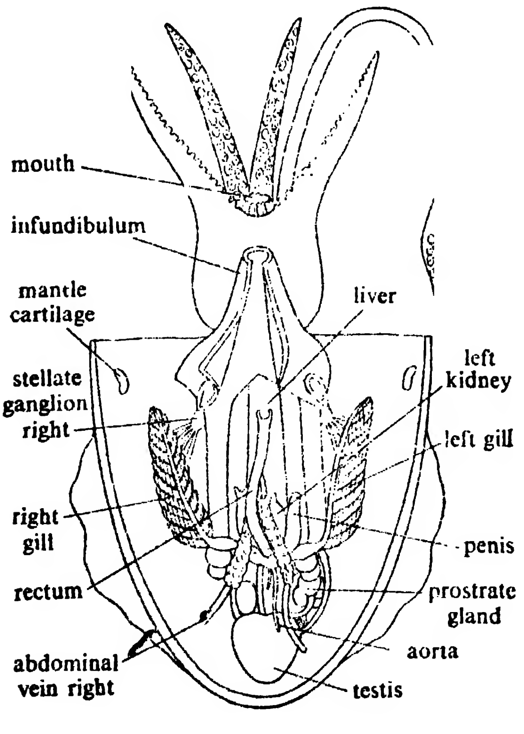


Fig. 17.38. Mantle cavity is opened from the ventral side in *Sepia* to show the disposition of internal structures.

margin of the body has lateral, thin, muscular folds called the fins.

The shell is internal and is bilaterally symmetrical. The shell is a flat ovoidal structure and is composed mostly of calcareous matter. It supports the body as an endoskeleton and is also known as *cuttle bone*. Living Sepia can change its colour due to the presence of *chromatophores* in the integument.

Sepia has a complicated structural organisation. A longitudinal incision of the mantle through the mid-ventral line will show the disposition of internal structures. The internal organs occupy the major portion of the mantle cavity (Fig. 17.38).

Coelom

The true coelom is represented by the viscero-pericardial coelom and the cavities in the kidney. The viscero-pericardial coelom is divided into two parts -the anterior is the pericardial cavity and the posterior is the gonocoel.

Digestive system

Sepia feeds on small fish and crustacea specially prawn. The circlet of eight short arms help in capturing the prey and bringing it to the mouth. The mouth is bounded by a circular lip within which a pair of powerful jaws are lodged. The jaws help in cutting the food into small bits. The circular lip is provided with many papillae. Mouth leads into the buccal cavity possessing an *odontophore* and the *radula*. The radula is relatively weak. The buccal cavity descends as a straight narrow tube called *oesophagus*, which in turn opens into a round *stomach*. The stomach is represented by two separate chambers communicating by a sphincter. The first chamber is called *gizzard*. It is muscular and strongly-built. The other chamber is the *caecum*. It is thin-walled. The caecum leads into the *intestine*. The intestine runs parallel to the oesophagus, continues towards the oral end as *rectum* and ultimately terminates into the mantle cavity by *anus* (Figs. 17.39 and 17.40). Two pairs of salivary glands are present. The anterior pair of salivary glands produce mucus. The posterior pair may show the tendency towards fusion and produce mucus, digestive enzyme (protease) and a number of poisons (indolic and phenolic amines).

Two sets of digestive glands are present. The ducts of the digestive glands open at the junction of the two chambers of the stomach. Of the two sets of digestive glands, the larger one is formed by the

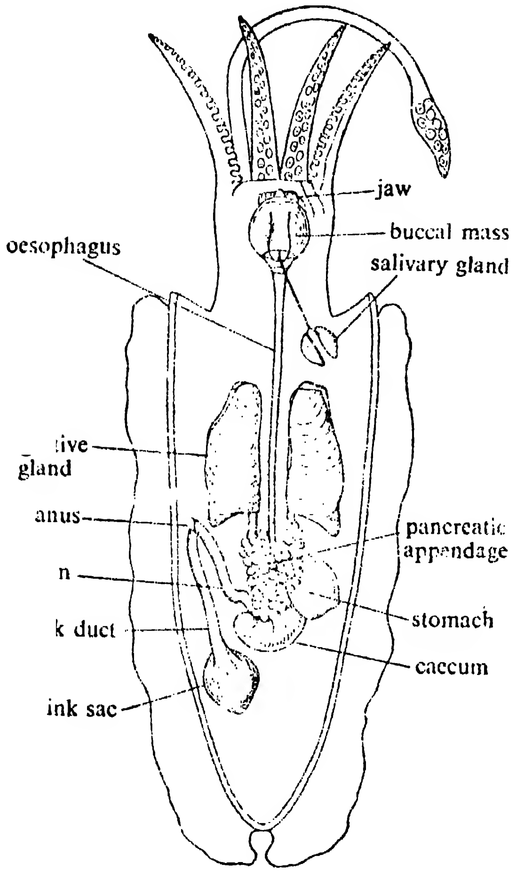


Fig. 17.39. Digestive system of *Sepia*.

fusion of a pair of brownish glandular lobes. The ducts from the larger one enter into the stomach near the point of origin of caecum. These glands are called *liver*. The other gland is clustered round the paired ducts of the liver. It is small, wedge-shaped, creamy in colour and follicular in appearance. It is called the *pancreas* and it opens into the gizzard.

A cylindrical duct coming from the ink-sac opens into the rectum. The ink-sac is a pear-shaped body (Fig. 17.41). The inner glandular mass secretes blackish ink. The ink is forced out to produce a coloured surrounding under the cover of which the animal can escape the sight of enemies.

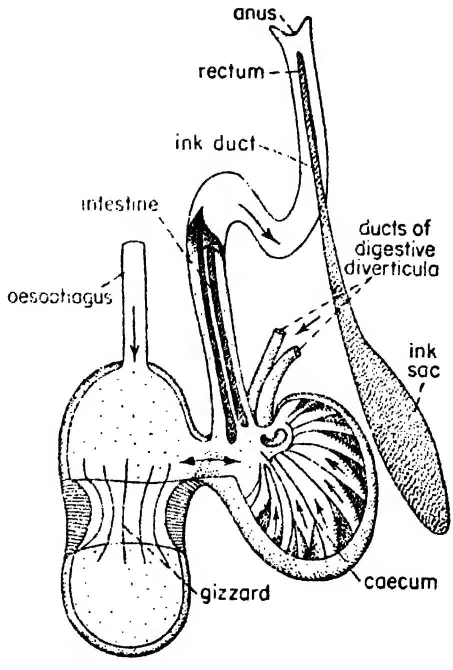


Fig. 17.40. Showing the interrelationship between the gizzard, caecum and ink-sac in *Sepia* (after Parker and Haswell).

Locomotion

Sepia is a good swimmer. It swims by the undulatory movement of the lateral fins. During rapid movement, sepia moves backward by sudden forceful expulsion of water like a jet from the mantle cavity through the siphon.

Respiratory system

The respiratory organs are the *ctenidia*. They are two in number. They are plume-shaped structures having numerous paired, delicately folded lamellae (see Fig. 17.38). Such a type of ctenidium is called bipectinate type. They are attached throughout the greater part of the mantle wall. The blood flows into the ctenidium by afferent branchial vessels and returns to the auricle by efferent branchial vessels.

Circulatory system

The circulatory system is highly developed in Sepia (Fig. 17.42). The heart consists of two auricles and one ventricle which is constricted into two lobes. The ventricle gives off anteriorly an *oral* or *anterior aorta* and a smaller *aboral* or *posterior aorta* in the

posterior side. The arteries arising from the two aortae supply the various parts of the body. Blood from the different parts of the body is collected into a large *vena cava*. The

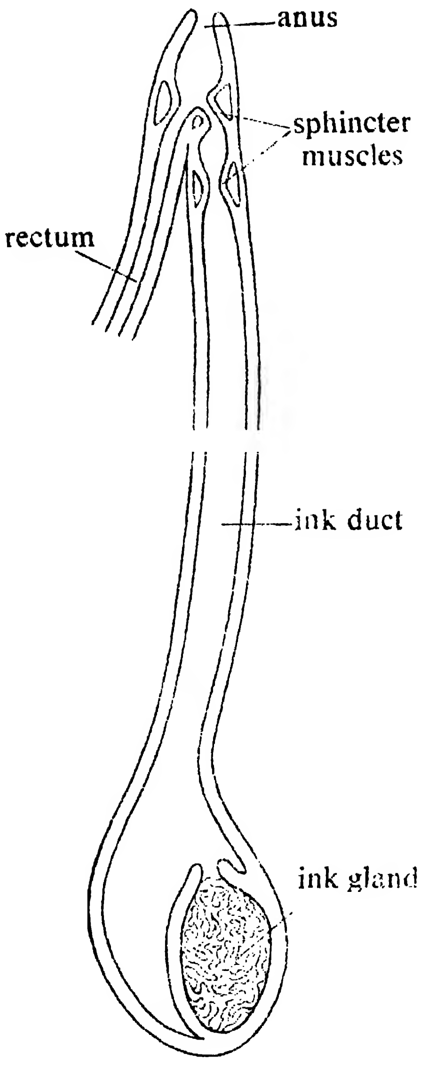


Fig. 17.41. Longitudinal sectional view of ink-sac in *Sepia*.

vena cava bifurcates anteriorly into *pre-cavals* which pass through the substance of the kidney and continue as *afferent branchial veins* supplying the ctenidia. The afferent branchial veins at the base of ctenidium dilate to form a contractile *branchial heart*. Attached to the branchial heart there exists a rounded glandular appendage. From the ctenidia blood returns to the heart by efferent branchial veins.

Excretory system

The excretory system consists of a pair of thin-walled *renal sacs* which communicate with the mantle cavity by two separate apertures, one in each side. The right and left sacs communicate with each other both anteriorly and posteriorly. Through each sac runs the corresponding branchial vein. Surrounding the branchial vein there are masses of glandular tissue of the renal sac. This glandular tissue extracts the nitrogenous waste from the blood in the form of *guanin*.

Nervous system

The nervous system is highly developed in Sepia. The cerebral, pedal, pleural and visceral ganglia are large in size and are closely aggregated around the oesophagus by shortening of their connectives (Fig. 17.43). They are all protected by cranial cartilaginous box. The cerebral ganglia are fused to form a single rounded mass and give off laterally the optic nerves which become expanded into optic ganglia. Another pair of nerves emerging from the cerebral ganglia are connected with the *superior buccal ganglia*. The superior buccal ganglia are also connected with the *inferior buccal ganglia* located on the posterior side of oesophagus. The pedal ganglia, like the cerebral, are also fused into a single mass which is differentiated anteriorly into a brachial portion giving origin to ten brachial nerves supplying the arms and posteriorly into the infundibular portion supplying nerves to the funnel and statocysts. The brachial nerves are connected with one another by ring commissure. The pleuro-visceral ganglia are also united to form a single ganglionic mass and remain in immediate contact with the pedal. The pleuro-visceral mass gives off a pair of *visceral nerves* supplying the viscera and also gives a *branchial nerve* to the ctenidium. The branchial nerve possesses a *branchial ganglion* at its base. The pleuro-visceral ganglion also gives two very stout nerves posteriorly. These two nerves are called the *pallial nerves* containing a large *stellate ganglion* on each nerve (for diagram see Fig. 17.59E in the general notes on the phylum). The inferior buccal ganglion gives off *sympathetic nerve* which terminates into a *gastric ganglion* located on the dorsal side of the stomach.

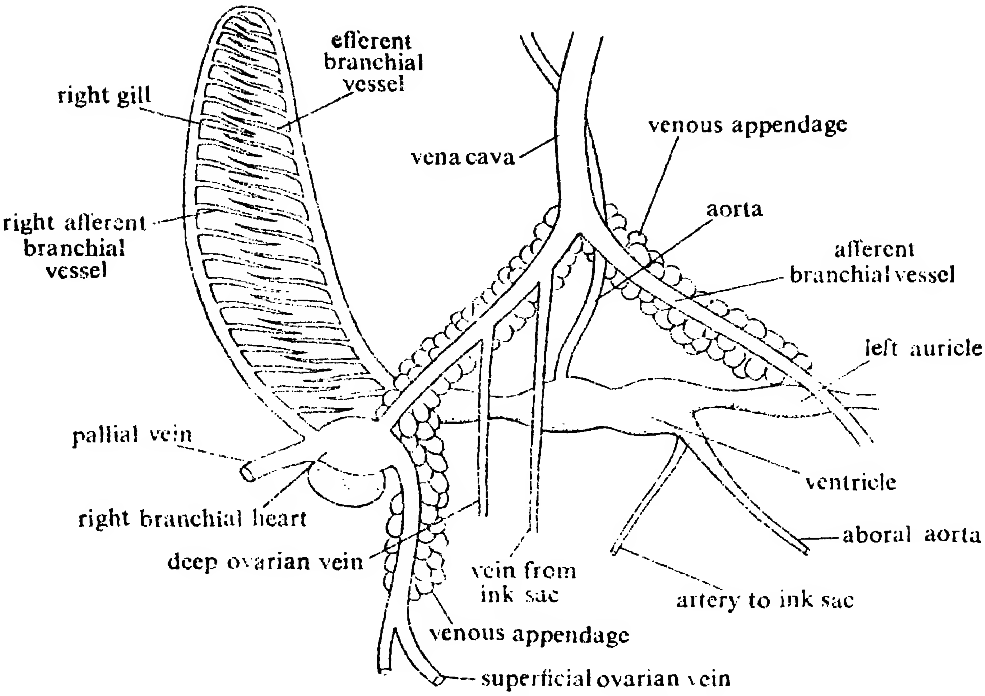


Fig. 17.42. Circulatory system of *Sepia*.

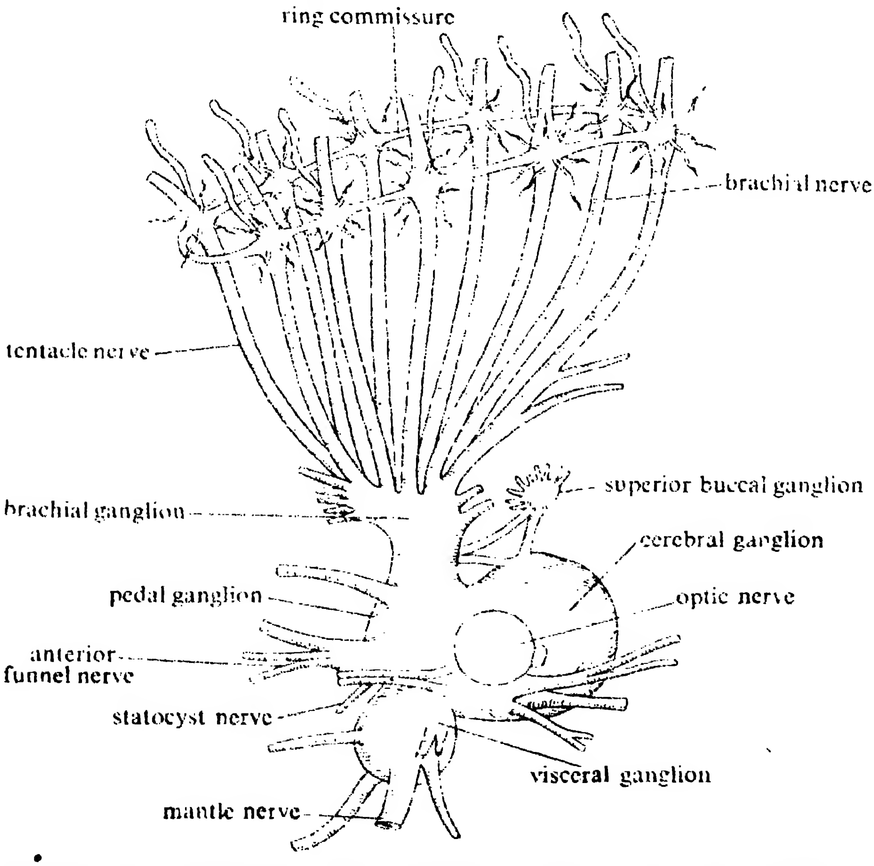


Fig. 17.43. An enlarged view of the proximal part of the nervous system of *Sepia*.

Sense organs

The sense organs are highly developed in Sepia. *Eyes:* They are highly developed. The eye ball has stout outer wall called *sclerotic* layer, which is provided with sclerotic plates. Other structural elements, viz. the cornea, lens, aqueous and vitreous humors, retina are present in the eye of Sepia (Fig. 17.44).

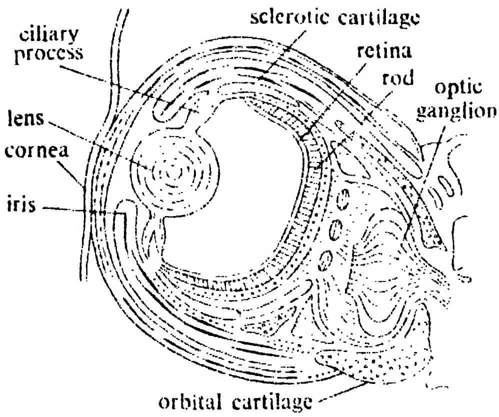


Fig. 17.44. Sectional view of the eye of *Sepia*.

Statocyst: The statocysts are two in number and are situated very close to the pleuro-visceral ganglion. They have complicated structures comprising of a *crista statica* and a *macula statica*. The crista statica and macula statica are rounded elevations on the inner cavity of the statocyst. The crista statica is lined by flattened epithelium and the macula statica is composed of elongated cylindrical cells with hair-like processes at the free ends. A very large statolith is present in the cavity which is attached to the macula.

Olfactory pits: In addition to eyes and statocysts, a pair of ciliated pits located behind the eyes, are supposed to be olfactory in function.

Gustatory organ: This organ for taste comprises of an elevation in front of the odontophore.

Besides these, the arms and tentacles are regarded as tactile organs.

Reproductive system

The sexes are separate. Sexual dimorphism is present. The males are distinguishable by the presence of hectacotylized arm.

Male reproductive system. The male reproductive system consists of a *testis* which is enclosed in a capsule. The capsule leads into an elongated and greatly convoluted *vas deferens* (Fig. 17.45A). The vas deferens opens into an elongated *seminal vesicle*. The seminal vesicle at the other end expands into a wide *sperm sac* which opens into the mantle cavity. The *prostate* is glandular and opens into the seminal vesicle at this end. The gonopore lies on an elongated papilla called *penis*. Inside the seminal vesicle sperms are rolled up and become enclosed by a chitinoid capsule which is called spermatophore (Fig. 17.45B).

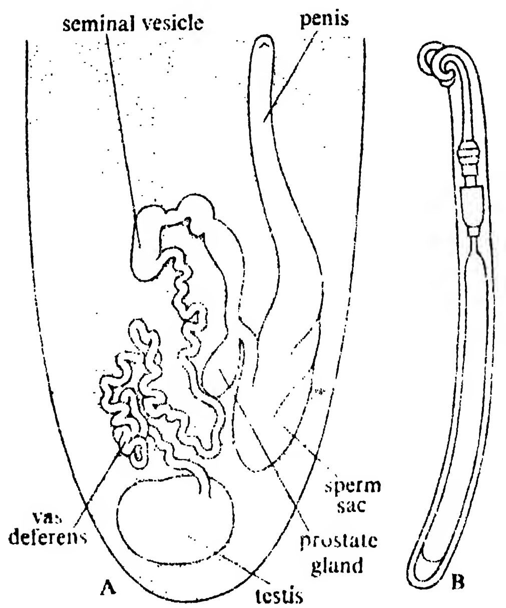


Fig. 17.45. A. Male reproductive organs of *Sepia*. B. A spermatophore of *Sepia*.

Each spermatophore is elongated and about 16 mm in length. Two-thirds of it house the viscous mass of sperm and the anterior one-third contains a spring apparatus. The outer wall of the spermatophore is made up of chitinised *capsule* and the inner wall forms the *tunic*. All the spermatophores remain stored in a pouch called Needham's sac. The hectacotylized arm takes out the spermatophores, keeps them for some time in the suckers and after the ritual of courtship places them on the body of the female.

Female reproductive system. Female reproductive system consists of a single *ovary*.

It is enclosed in a capsule which leads into a wide tubular oviduct. The oviduct opens into the mantle cavity near the rectum (Fig. 17.46A). A pair of *nidamental glands* are present on the sides of the ink-duct. They are oval in shape and their secretion helps the eggs to adhere together like a bunch of grapes (Fig. 17.46B). Another

Solen

Solen is a burrowing bivalve and is generally called 'Razor shell'. The body is narrow and is covered by two thin, equal and straight shell valves (Fig. 17.47B). The umbo is shifted at the anterior end. One peculiar feature in this genus is the presence of a single hinge

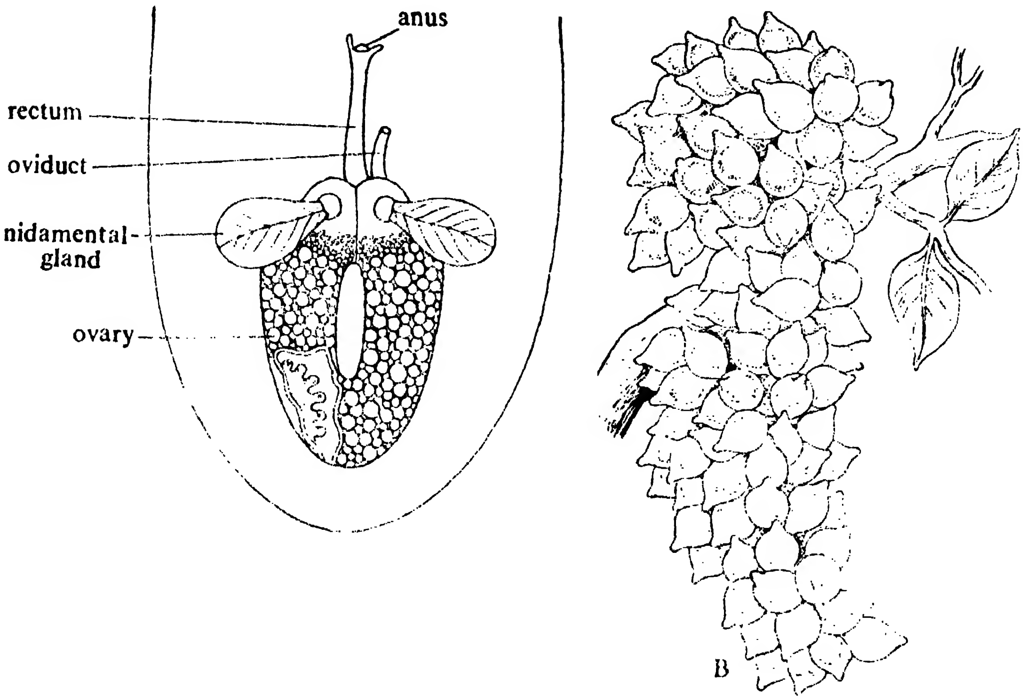


Fig. 17.46. A. Female reproductive organs of *Sepia*. B. Cluster of eggs of *Sepia* attached to a twig.

accessory nidamental gland of unknown function is present around the anterior ends of the nidamental glands proper.

Development

The development of *Sepia* is direct, because the young emerges out of the egg and looks like the adult. The fertilized egg is enveloped by a protective gelatinous covering. The eggs are very large in size. They are pear-shaped and are heavily yolked. The yolk provides nourishment for the developing embryo.

SOME INTERESTING MOLLUSCS

Besides the typical examples of the Phylum Mollusca, the following forms are described to gain a first hand knowledge of the peculiar molluscan forms.

tooth in each shell valve. The mantle cavity is tubular and is formed by the fusion of the mantle lobes on the ventral side. The exhalant and inhalant siphons are small. There are a pair of elongated narrow gills in the mantle cavity. The foot is a highly muscular elongated organ which forms an efficient burrowing apparatus. The foot swells up very quickly by the inflow of blood during burrowing.

Pecten

Pecten, commonly called 'Scallop', is a cosmopolitan marine bivalve (see Fig. 8.11A). It feeds on micro-organisms caught during respiratory water current. The two shell valves are slightly unequal in size. The right valve is larger, convex in shape and the soft parts lie within this valve. The

outer surface of the valves exhibits radiating striations and the concentric lines of growth take a wavy course. The shell is beautifully sculprured. The hinge line between the shell valves is straight and is devoid of teeth. The margin of the mantle produces velar folds with numerous tentacles and stalked eyes at regular intervals. Only one large median adductor muscle is present. The foot is extremely reduced. It can swim by the activities of the shell valves.

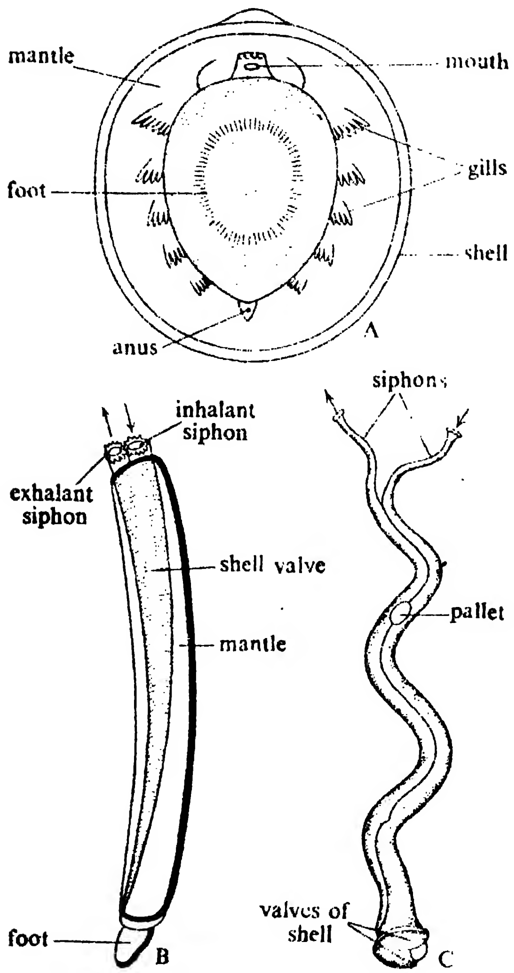


Fig. 17.47. External features of: A. *Neopilina galatheae* (ventral view). B. *Solen*. C. *Teredo*.

Mytilus

This sea-mussel is a sedentary bivalve (see Fig. 8.11F) of cosmopolitan distribution. The valves of the shell are broad and rounded at the posterior side and the anterior end is narrower. The umbo is shifted to the anterior side. Both the siphons are present but the inhalant siphon is less developed. The posterior margin of the mantle is fringed with tentacle-like processes. The foot is elongated. The animal remains attached to the substratum by a bunch of byssus threads. The byssus threads project from the ventral side between the valves. The posterior adductor muscles are more developed than the anterior ones. The interlamellar and interfilamentar junctions are absent and are represented by a bunch of cilia.

Teredo

This peculiar bivalve is well-known for causing tremendous damage to the ships and dock. It lives in holes made in the submerged portion of ship and wood. Because of its boring habit the body of *Teredo* has become extremely modified. It has an elongated vermiform body and is popularly called as the 'Shipworm' (Fig. 17.47C). The shell valves are very small and are situated in the anterior end of the body. The shell has a rough surface which acts as the cutting and boring machine. It has a very minute foot reduced into a sucker to adhere to the wall of the hole. The sucker projects through a small aperture left by the mantle lobes and the rest of the mantle lobes are united. The mouth is situated between the shell valves. The body proper and the inhalant and exhalant siphons are extremely elongated. The siphons are united at the anterior side and the posterior portions are free. Just at the region of separation of the siphons there lie a pair of calcareous *pallets* which close the opening of the hole like a lid when the body and the siphons are withdrawn.

Teredo feeds on sawdust and small plankton brought by respiratory water current. It has the remarkable property of digesting the cellulose.

Aplysia

Aplysia is a very peculiar gastropod and has almost a cosmopolitan distribution. It is recorded that it attains a size of about 1 m in length. Because of the superficial resemblance with hare, particularly in the head region, it is commonly called the 'Sea-hare' (Fig. 17.48A). The head bears two pairs of tentacles. The posterior

pair is comparatively smaller and is called *rhinophores*. These are olfactory in function. The anterior pair of tentacles are longer in size and are called *cephalic tentacles*. The foot is broad and bears lateral projections called *parapodia* as the organs of swimming. The foot gives origin to a very short, distinct tail at the posterior end. The posterior part of the foot is usually adhesive. The mantle is extended upwards as a thin membrane and the shell is concealed by the mantle outgrowth. The shell is reduced to a small flattened piece which is internally placed. The mantle cavity opens to the right side of the body through a longitudinal slit. The ctenidium is visible along the opening of the mantle cavity. The floor of the mantle is provided with large subepithelial gland cells called *opaline glands*. *Aplysia* is notable for discharging purple or milky fluid to the surrounding water to conceal itself from enemies. This fluid is secreted by another type of gland in the inner mantle epithelium, called *Blochmann's glands*. The nervous system is of ethyneurous type, i.e. attainment of secondary symmetry after double torsion. They are bisexual forms producing both sperms and eggs. The gonoduct is single and opens to the exterior through a common genital opening.

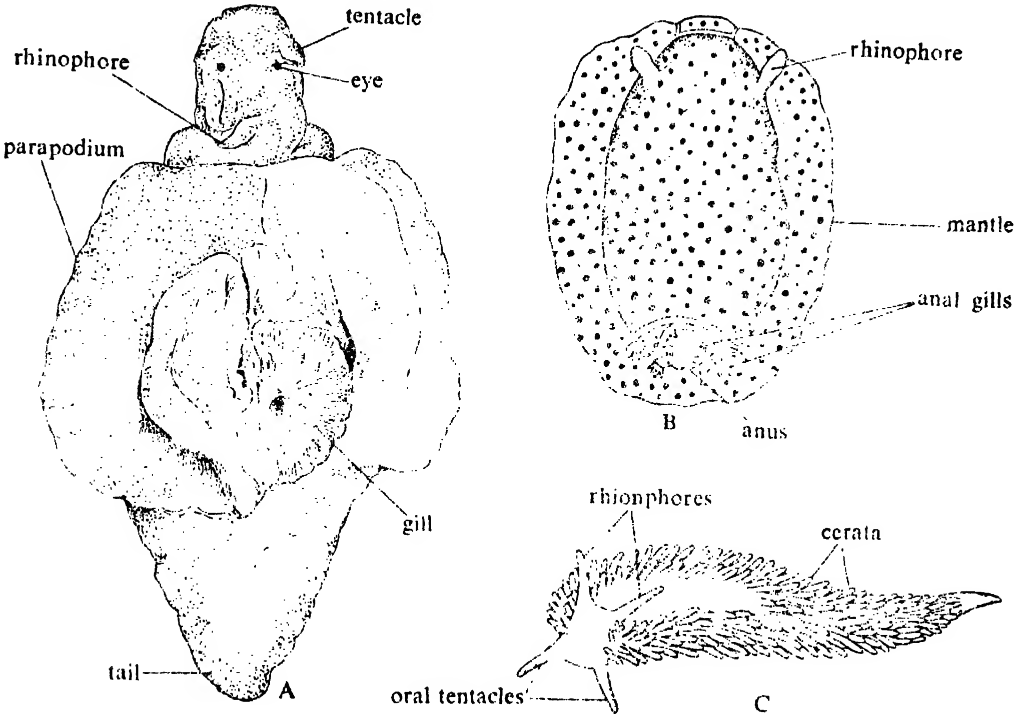


Fig. 17.48. External features of : A. *Aplysia*. B. *Doris*. C. *Aeolis*.

Doris

Doris, popularly called 'sea-lemon', is a curious gastropod (Fig. 17.48B), where the shell and ctenidium are totally absent. The anus is located posteriorly and is mid-dorsal in position. It is surrounded by a circlet of *anal gills* which act as respiratory organs. The body of *Doris* comprises in a more or less ovoid mass with a convex warty dorsal side. The head bears a pair of *rhinophores* beset with calcareous spicules. The foot has a flat creeping sole. The digestive gland is an unbranched compact mass. The nervous system is of ethyneurous type. The sexes are united and the gonopore is asymmetrically placed on the right side of the body.

Aeolis

Like Doris, *Aeolis* is also a nudibranch. It has an elongated shell-less body. It has two pairs of tentacles, the anterior pair are called *cephalic tentacles* and the posterior pair are designated as *rhinophores* (Fig. 17.48C). The rhinophores are simple.

The radular tooth is arch-like and is devoid of median notch. True gills are absent and respiration is done through transverse rows of secondary cylindrical *cerata*. The cerata open to the exterior through openings.

Aeolis feeds on sea-anemones. The *cnidoblasts* of the anemones taken inside the body of *Aeolis* usually escape digestion and migrate to the tips of the cerata. These are called the *cnidosacs* which probably act as defensive organs. It is claimed by many that on proper irritation the cnidosacs discharge their contents towards the prey or enemies. But such a phenomenon is not witnessed by any worker. However, existence of cnidosacs in the body of *Aeolis* is a unique instance and the significance of cnidosacs in the body of *Aeolis* is not fully understood.

Onchidium

This curious slug-like gastropod had long been considered to be a pulmonate, but recently it has been separated from them and placed under Opisthobranchia. As regards habits and general appearance, *Onchidium* resembles superficially the chitons. Like other gastropods two pairs of tentacles are present. It has an ovoid naked body. The foot has a very broad flat creeping sole. The mantle covers the dorsal side of the body and is beset with numerous warty tubercles. These warty bodies may bear eyes and may also transform into bunch of branchial filaments as respiratory organs. The true ctenidium and mantle are lacking. The head possesses two retractile tentacles, each ending in an eye (Fig. 17.49A). A pulmonary chamber is present in the posterior part of the body. The sac opens to the exterior through a small aperture (*pneumostome*) near the anal opening. *Onchidium* is hermaphrodite. The female gonopore is situated posteriorly near the anal opening, while the male genital aperture is located anteriorly near the base of the right retractile tentacle.

Patella

Patella is a small, sluggish gastropod inhabiting the rocky beaches. *Patella* lives upon marine vegetation. The dorsal side of the body is enclosed by a roundish shell. The shell is raised into a conical elevation. The operculum is absent. The ventral side of the body is occupied by a broad creeping foot (Fig. 17.49B). The foot is also employed as an adhering organ. The mantle is

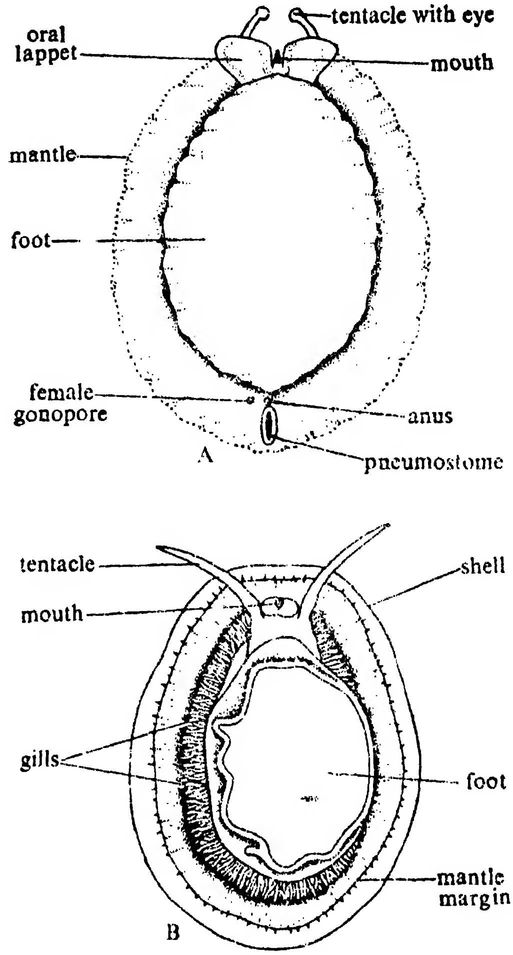


Fig. 17.49. External features (ventral view) of: A. *Onchidium*. B. *Patella*.

highly pigmented. The head bears a pair of large sensory tentacles and a pair of eyes. Between the foot and mantle, there exists a series of secondary branchiae. The primary gills are obliterated excepting a pair of vestiges. A pair of osphradia and a pair of oesophageal pouches are present. It has a single auricle. There are two kidneys, of which left one is smaller in size. Sex reversal is very common in *Patella*. Fertilization is external.

Spiratella (Limacina)

Spiratella is a typical pteropod. Like all other forms, *Spiratella* leads pelagic life and swims by flapping the parapodia. The foot develops anteriorly into highly muscular wing-like projections called

parapodia (Fig. 17.50A). The posterior part of the foot is greatly reduced. It has a spirally coiled calcareous shell and an operculum is present. The shell assumes various shapes in other related genera. *Spiratella* has a dorsal mantle cavity but without ctenidium. They usually swim in large numbers and are generally called the 'butterflies of the sea'.

Cypraea

This type of gastropod is a very familiar form of mollusc. The shell of this form is used as curio, ornament and as decorative article. It was used as currency in ancient days. It is a very beautifully coloured form living on rocky background, specially in the coral reefs. The shell has a large oval single whorl. The dorsal side is convex and the ventral side is flat with a narrow longitudinal opening extending along the length of the shell (Fig. 17.50B). This opening is toothed on both sides. The lateral sides of the mantle folds are reflected over the dorsal side of the shell to make it internal.

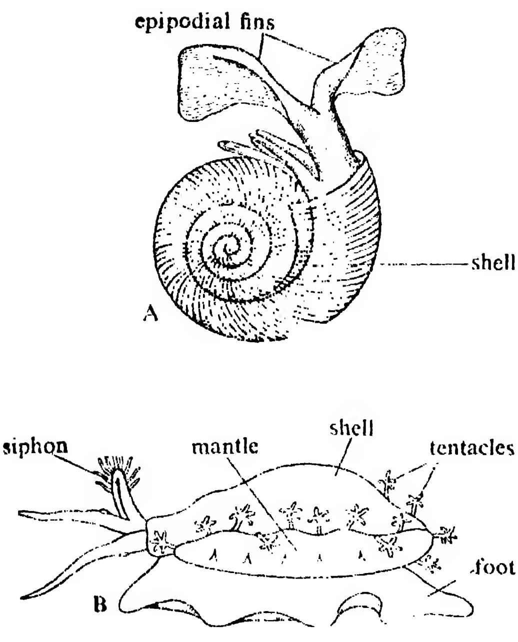


Fig. 17.50. External features of: A. *Spiratella*. B. *Cypraea*.

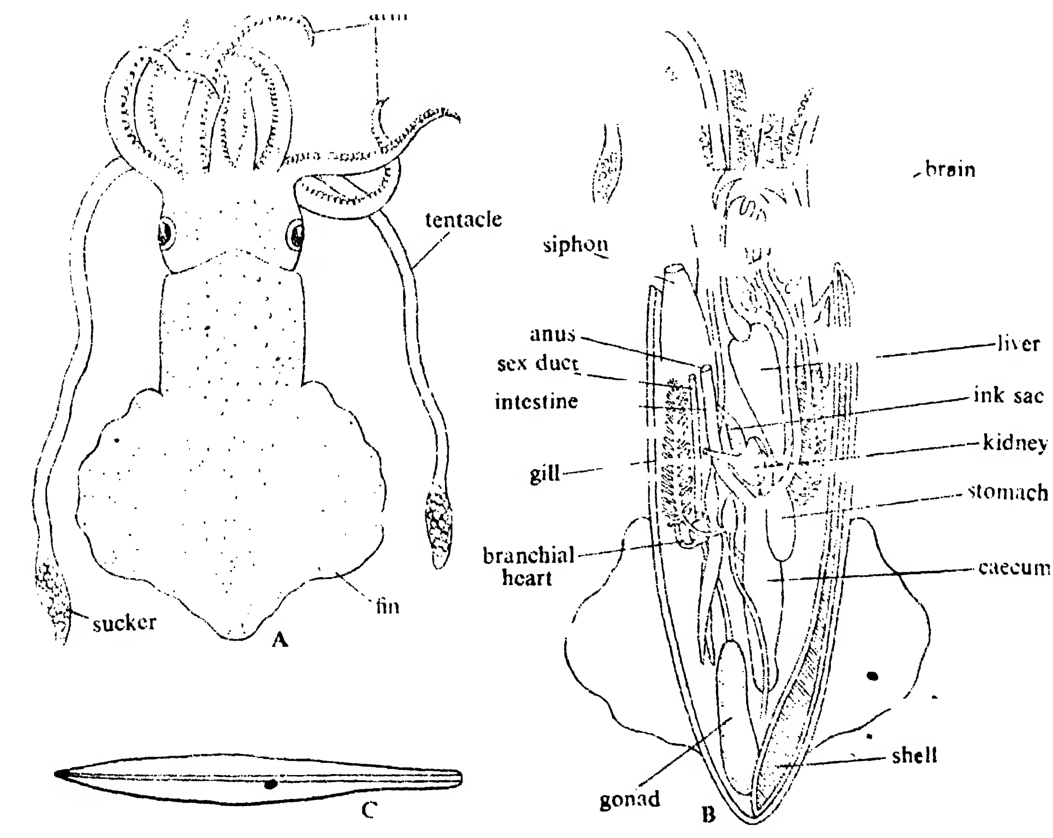


Fig. 17.51. Structures of *Loligo*. A. Dorsal view of an entire animal. B. Dissected ventrally to show the disposition of internal structures. C. Shell.

The shell lacks periostracum and the surface is smooth.

Loligo

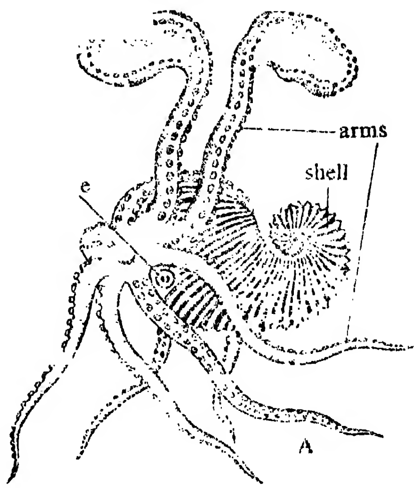
Loligo is a very common cephalopod and is commonly called squid. It has almost the same anatomical organisation as that of *Sepia*, but it possesses certain individual peculiarities. *Loligo* has an elongated spindle-shaped or torpedo-shaped body (Fig. 17.51A). The body is divided into head, tapering trunk and a narrow neck between them. The head bears ten arms of which eight are short and two are usually elongated like those of Sepia. The fins are conical and are confined to the posterior end of the body. Figure 17.51B shows the internal organisation of *Loligo*. The shell is internally placed and resembles old styled quill-pen (Fig. 17.51C). The caecum is very large in size and bears an anterior curved diverticulum. The liver is a single lobed structure. An ink-sac is present. The heart consists of two auricles and a single ventricle. An additional rounded branchial heart is present at the base of each gill. The excretory system comprises in two triangular whitish bodies called kidneys. The nervous system is highly developed and resembles closely the nervous system of Sepia.

Octopus

Octopus, popularly called devil fish, is a very well-known molluscan form. It has a cosmopolitan distribution and lives at the bottom of the sea. It is nocturnal and lives on crabs, fishes and other molluscs. It has a roundish body with a head. The shell is absent. Eight elongated arms of equal sizes are present (see Fig. 8.11B). Each arm carries two longitudinal rows of sessile suckers. In male Octopus the third right arm is modified into a spoon-shaped hectocotylized arm. The animal can crawl by its arms and can also swim backward by ejecting jet of water from the funnel. Octopus has the ability of ejecting inky fluid to the surrounding water as a defensive device. *Octopus* has the property of changing the colour of the body when it is irritated. The nervous system is highly developed.

Argonauta

Argonauta, popularly known as 'Paper Nautilus', is closely related to Octopus. Sexual dimorphism is distinct in *Argonauta*. The male is much smaller than the female and lacks shell. But the female is very large in size and possesses a thin fragile external shell (Fig. 17.52A). The shell is



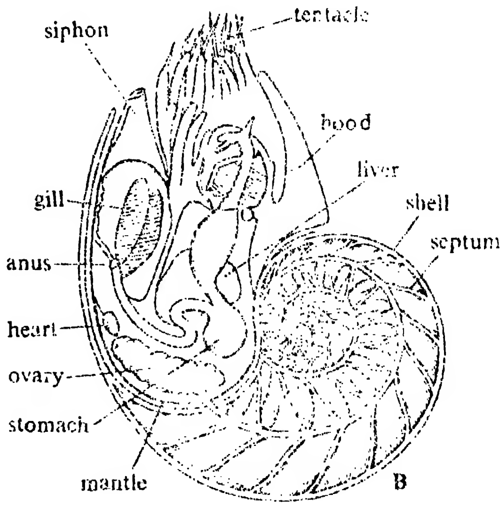


Fig. 17.52. A. A female *Argonauta*. B. Sectional view of *Nautilus*.

symmetrical, simply coiled and lacks internal septa. The shell is mainly used to carry eggs. Of the eight arms, two dorsal arms become specialised and become applied to the outer surface of the shell. The terminal end of these two arms become expanded to form disc-like structure. The shell in females *Argonauta* is secreted by these two arms and is not produced by the mantle as the case in other molluscan forms. Like that of Octopus, the third right arm in males is hectocotylized.

Nautilus

Nautilus is gregarious, deep-sea inhabitant, nocturnal cephalopod found in Indian and Pacific Oceans. It is popularly called the 'Pearly Nautilus'. The external shell is flat and coiled spirally in one plane. It is divided internally into many compartments by internal septa (Fig. 17.52B). The chambers increase in size from inner to the outer side of the spiral, i.e. the outermost chamber is the largest. The body proper is lodged in the largest chamber and the other chambers remain either empty or filled up with gas which helps in floatation. The internal septa bear perforation in the middle.

The mouth is surrounded by radially arranged prehensile tentacles. The number of tentacles varies from 60 to 90. The tentacles are devoid of suckers. On the dorsal side, two tentacles become thicker to form a protective hood above the mouth. The outer surface of the shell has alternate brown and dark bands. The inner surface is pearly white. The ink-sac is absent.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

Class **Monoplacophora,**
e.g. *Neopilina.*

Class **Amphineura**
Subclass Aplacophora
Order *Chaetodermomorpha*, e.g. *Chaetoderma.*
Order *Neomeniomorpha*, e.g. *Neomenia, Proneomenia.*
Subclass Polyplacophora
Order *Lepidopleurina*, e.g. *Lepidopleurus.*
Order *Chitonina*, e.g. *Chiton.*

Class **Scaphopoda,** e.g. *Dentalium.*

Class **Bivalvia** or **Pelecypoda**
Order *Protobranchiata*, e.g. *Nucula.*
Order *Filibranchiata*, e.g. *Mytilus.*
Order *Pseudolamellibranchiata*, e.g. *Ostrea.*
Order *Eulamellibranchiata*, e.g. *Unio.*
Order *Septibranchiata*, e.g. *Poromya.*

Class **Gastropoda**
Subclass Prosobranchia
Order *Archaeogastropoda*, e.g. *Patella, Fissurella.*
Order *Mesogastropoda*, e.g. *Pila, Atlanta.*
Order *Stenoglossa* or *Neogastropoda*, e.g. *Murex, Bullia.*
Subclass Opisthobranchia
Order *Onchidiacea*, e.g. *Onchidium, Onchidella.*
Order *Cephalaspidea*, e.g. *Acteon, Rhizorus.*
Order *Anaspidea*, e.g. *Aplysia, Akera.*
Order *Pteropoda*, e.g. *Spiratella, Desmopterus.*
Order *Acochlidiacea*, e.g. *Acochlidium, Unela.*
Order *Philinoglossacea*, e.g. *Philinoglossa, Pluscula.*
Order *Sacoglossa*, e.g. *Oxynoe, Elysia.*
Order *Notaspidea*, e.g. *Tylodina, Pleurobranchus.*
Order *Nudibranchia*, e.g. *Doris, Kalinga.*
Order *Rhodopacea*, e.g. *Rhodope.*
Order *Pyramidellacea*, e.g. *Pyramidella, Brachystomia.*
Order *Parasita*, e.g. *Entoconcha, Entocolax.*
Subclass Pulmonata
Order *Basommatophora*, e.g. *Planorbis, Limnaea.*
Order *Stylommatophora*, e.g. *Helix, Achatina.*

Class **Cephalopoda**
Subclass Belemnoidea or Dibranchiata
Order *Decapoda*, e.g. *Sepia, Loligo.*
Order *Octopoda*, e.g. *Octopus.*
Subclass Nautiloidea or Tetrabranchiata, e.g. *Nautilus.*
Subclass Ammonoidea, e.g. Ammonites.

CLASSIFICATION WITH CHARACTERS

Class **Monoplacophora**

This class is represented by a recently discovered living species, *Neopilina galatheae.* It is very primitive amongst the molluscs and represents a sort of connecting link between annelids and molluscs. This class also contains many fossil forms. The body is bilaterally symmetrical and remains covered by a mantle. The dorsal side of the body contains a single piece of shell. The body exhibits internal metamerism. The whole of the ventral side is occupied by a flat creeping foot. The coelom is well-formed. Most of the structures like auricles, gills, kidneys and gonads are segmentally arranged. The mouth

and anus are situated at the antero-median and postero-median ends of the foot respectively.

Class **Amphineura**

This class includes a small group of marine molluscs having bilaterally symmetrical elongated body. The mouth and anus are terminally located. The nervous system represents the primitive condition having longitudinally disposed pallial and pedal nerve cords with cross-connections.

This class includes two subclasses. They are:

Subclass: Aplacophora. This subclass represents a very small group of molluscs. They are marine. They have elongated bilaterally symmetrical, worm-like bodies covered by cuticle. The cuticle bears calcareous spicules. The body lacks a distinct head. The shell and foot are totally absent. The intestine is uncoiled. The vascular system is rudimentary. The nervous system is primitively built and consists of two pedal and two pleural nerve cords which are connected anteriorly with an oesophageal nerve ring. The cerebral ganglion is either single or double. The sex cells are discharged into the pericardial cavity.

The subclass Aplacophora has two orders: Neomeniomorpha and Chaetodermomorpha.

Order *Neomeniomorpha*. This order has a mid-ventral longitudinal groove which helps in locomotion. The sexes are united. Examples: *Neomenia*, *Proneomenia*.

Order *Chaetodermomorpha*. The mid-ventral groove is lacking in this order. The sexes are separate. Example: *Chaetoderma*.

Subclass Polyplacophora

The members of this subclass have bilaterally symmetrical untorted bodies. The body is dorso-ventrally flattened. The dorsal side is convex and the ventral side is flat. The dorsal side of the body is covered by eight pieces of transversely placed shell. The pieces are arranged in an imbricate fashion. The head is inconspicuous and the eyes and tentacles are absent. Many external gills are located in the mantle groove and a pair of kidneys is present. This subclass is divided into two orders: Lepidopleurina and Chitonina.

Order *Lepidopleurina*. The valves of the shell are usually devoid of insertion plates. The insertion plates, present in rare cases, are without teeth. The gills are limited towards the posterior end of the body and are a few in number. Examples: *Lepidopleurus*, *Hanleya*, *Hemiarthrum*, *Choriplax*.

Order *Chitonina*. The valves of the shell are provided with toothed insertion plates. The gills are usually distributed along the whole length of the mantle groove. Examples: *Chiton*, *Chaetopleura*, *Nuttallina*, *Tonicella*, *Loricata*, *Mopalia*, *Acanthopleura*.

Class **Scaphopoda**

The class Scaphopoda constitutes an aberrant group of marine molluscs comprising of *Dentalium* and *Pulsellum*. The body is elongated and appears as a complete bilaterally cylindrical tube enclosed by a shell. The shell is a delicate and slightly curved tube. The shell is open at both the ends and the anterior part of the shell is much wider (Fig. 17.53). The foot

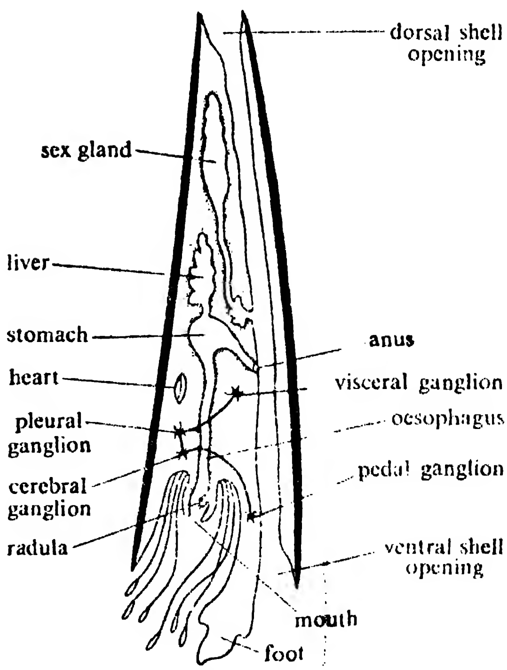


Fig. 17.53. Longitudinal sectional view of *Dentalium*.

is very narrow, trilobed and is capable of being protruded through the anterior opening of the shell. The mouth is situated on the oral proboscis. The gonad is an elongated structure and is unpaired. Nervous

system has paired cerebral, pleural, pedal and visceral ganglia. The kidneys are paired structures and lie in the middle of the body which open on either side of the anus.

Class **Bivalvia** or **Pelecypoda**

The members of this class have bilaterally symmetrical bodies. The body is enclosed by bivalved shell secreted by the mantle. The head is indistinct. The foot is tongue-shaped and is located ventrally. The mouth is provided with two pairs of labial palps.

The class is divided into five orders. The division into different orders is based on the nature of the respiratory structure.

Order *Protobranchiata*. The gills consist of two plume-like structures, each with two rows of gill filaments. Example: *Nucula*.

Order *Filibranchiata*. The gills consist of two V-shaped plate-like gill filaments. The interfilamentar and interlamellar junctions may be absent. Example: *Mytilus*.

Order *Pseudolamellibranchiata*. The gills are plaited. The interfilamentar and interlamellar junctions are present and are non-vascular. A single large adductor muscle is present. Examples: *Ostrea*. *Meleagrina*.

Order *Eulamellibranchiata*. The gill filaments are connected by vascular interfilamentar and interlamellar junctions. Two adductor muscles are present. Examples: *Unio*, *Anodonta*, *Lamellidens*.

Order *Septibranchiata*. The gills are reduced to a horizontal muscular partition. Examples: *Poromya*, *Cuspidaria*.

Class **Gastropoda**

This class owes its name to two Greek words *Gastros* =stomach and *podos* =foot. The members of this class have asymmetrical bodies due to torsion or detorsion. Usually they have spirally twisted shell. The coiling of the shell is usually *dextral* although *sinistral* type is observed in some normal and in abnormal cases. The mantle and the mantle cavity are distinct. The head is well-differentiated bearing eyes and tentacles. The buccal cavity contains an *odontophore* and a *radula*. The intestine is much coiled. The foot is well-formed and is situated behind the head. The foot is generally differentiated into three parts - ***propodium***, ***mesopodium*** and ***metapodium***.

The class Gastropoda is divided into three subclasses—Prosobranchia or Streptoneura, Opisthobranchia and Pulmonata.

Subclass Prosobranchia or Streptoneura. The visceral hump is twisted due to torsion. As a consequence of torsion, the pleuro-visceral connectives are crossed like figure '8', hence the name Streptoneura (Gr. *Streptos* =curved and *neuron*=nerve). The gills, when present, are placed anterior to the heart, so the other name of the subclass is Prosobranchia. The shell and the operculum are present in most cases. The sexes are separate. This subclass has three orders: Archaeogastropoda, Mesogastropoda and Stenoglossa or Neogastropoda.

Order *Archaeogastropoda*. This order includes the primitive Prosobranchs. The siphon and proboscis are absent. The operculum is present in a few cases. Two auricles, two bipectinate gills, two nephridia, and two osphradia are generally present. The nervous system exhibits less concentration. The pedal ganglia give origin to two pedal nerve cords which are connected by numerous commissures. The genital products are discharged directly outside through the right kidney. Examples: *Pleurotomaria*, *Haliotis*, *Patella*, *Fissurella*, *Acmaea*, *Lottia*, *Nacella*, *Trochus*, *Neritina*.

Order *Mesogastropoda*. The siphon, operculum and penis are present. The nervous system lacks pedal nerve cords. Single auricle, single monopectinate gill, single osphradium and single kidney are present as the consequence of torsion. Examples: *Viviparus* (*Peludina*), *Pila*, *Valvata*, *Littorina*, *Oncomelania*, *Dendropoma*, *Cerithium*, *Cypraea*, *Natica*, *Janthina*, *Atlanta*.

Order *Stenoglossa* or *Neogastropoda*. The siphonal canal is much elongated. The radula is usually rachiglossate type, i.e. the teeth on the radular rows are bilaterally arranged with a median (*rachidian*) tooth and *lateral* and *marginal* teeth on two sides excepting the superfamily *Conacea*. Examples: *Murex*, *Nucella*, *Thais*, *Magilus*, *Buccinum*, *Phos*, *Bullia*, *Fusinus*, *Nassarius*, *Oliva*.

Subclass Opisthobranchia. This subclass comprises of exclusively marine gastropods with much reduced mantle cavity. The mantle cavity, when present, is retreated to the right side. The shell is usually reduced. The shell is without ornamentation and remains mostly covered by the mantle folds. Visible shell is a rare occurrence,

There is no operculum. Single auricle is present posterior to the ventricle. The nervous system shows anterior concentration of ganglia and the posterior part shows ethyneurous (Gr. *Euthus*=straight and *neuron*=nerve) condition. They are all hermaphroditic. This subclass has the following orders:

Order *Onchidiacea*. They have slug-like shellless bodies resembling superficially the chitons. Single pulmonary sac is present. The anus and female gonopore are situated at the posterior side while the male genital aperture is located at the anterior end. Examples: *Onchidium*, *Onchidella*.

Order *Cephalaspidea*. The presence of head shield is the most peculiar feature. The shell is present which remains partly or wholly within the mantle. The parapodial lobes are present. Examples: *Acteon*, *Cylichna*, *Bulla*, *Atys*, *Rhizorus*.

Order *Anapsidea*. The parapodial lobes are well-formed. The shell is reduced to a flattened plate and remains concealed in the mantle lobes. In *Akera*, the shell is external. The head bears a pair of cephalic tentacles and a pair of rhinophores. The male gonopore is situated at the base of the right rhinophore. Examples: *Aplysia*, *Petalifera*, *Notarchus*, *Bursatella*, *Akera*.

Order *Pteropoda*. Pelagic opisthobranchs with a pair of highly muscular wing-like parapodia. They are mostly shelled forms. The shell is placed externally and is of different types. Examples: *Spiratella*, *Cavolina*, *Corolla*, *Desmopterus*, *Pneumodermopsis*.

Order *Acochlidiacea*. They are very small and peculiar snails. The shell and gill are lacking. The visceral mass is separated from the foot. They are fresh-water forms and the sexes are separate. Examples: *Acochlidium*, *Hedylopsis*, *Unela*, *Ganitus*.

Order *Philinoglossacea*. They are similar to Acochilidiacea, but lacks cephalic appendages. The foot and the visceral mass are well separated by a groove. The shell and gill are absent. Examples: *Philinoglossa*, *Sapha*, *Pluscula*.

Order *Sacoglossa*. The shell may be present or absent. The pharynx is suctorial. The parapodia and cerata may be present. The sperm duct is closed. Examples: *Oxynoe*, *Lobiger*, *Elysia*, *Caliphylla*.

Order *Notospidea*. The shell may or may not be present. The mantle is present but without mantle cavity. The gill is bipectinate type. The gill and osphradium are located on the right side of the body. Examples: *Tylodina*, *Umbraculum*, *Pleurobranchus*.

Order *Nudibranchia*. The shell, mantle cavity, gill and osphradium are absent. The body bears numerous cerata or respiratory outgrowths. The nervous system shows concentration of different ganglia and the visceral loop is greatly reduced. Examples: *Doris*, *Cadlina*, *Jarunna*, *Kalinga*.

Order *Rhodopacea*. This order is represented by a single species, *Rhodope veranyi*. It has an elongated body without tentacles, branchial appendages, circulatory system and radula. The nephridiopore and the anus are located on the right side of the body.

Order *Pyramidellacea*. They are semiparasitic forms. A spirally coiled shell and an operculum are present. The gills and radula are lacking. A long retractile proboscis is present which contains a stylet to pierce the body of the prey. Examples: *Pyramidella*, *Odostomia*, *Brachystomia*.

Order *Parasita*. They are endoparasitic gastropods living inside the body of holothurians. They are extremely degenerated forms. Their gastropodan nature is established by the presence of shelled larval stage. Examples: *Entoconcha*, *Thyonicola*, *Entocolax*.

Subclass Pulmonata. The true gill is absent and respiration is done by pulmonary sac or lung. The nervous system is secondarily symmetrical due to detorsion. The shell may or may not be present. They are hermaphrodite. This subclass has two orders:

Order *Basommatophora*. The eyes are located at the base of the non-retractile tentacles. Examples: *Planorbis*, *Limnaea*, *Siphonaria*, *Pythia*.

Order *Stylommatophora*. The eyes are located at the tip of the posterior pair of retractile tentacles. Examples: *Helix*, *Limax*, *Achatina*, *Ena*, *Zebrina*, *Milax*.

Class **Cephalopoda**

Amongst all the molluscs, Cephalopoda has reached the highest grade of structural organisation. This group has a very well-formed head with eyes and arms. The body is bilaterally symmetrical. The foot is modified into oral arms and siphon for

swimming. The shell, if present, is usually internally disposed. All the cephalopods are marine. The class Cephalopoda is divided into three subclasses:

Subclass Belemnoidea (Dibranchiata)

This subclass includes the cephalopods possessing internal shell and two ctenidia, two auricles and two kidneys. The funnel is a complete tube.

Order *Decapoda*. The examples of this order are *Sepia* and *Loligo*. They possess ten oral arms with stalked suckers.

Order *Octopoda*. The example is *Octopus* possessing eight arms with sessile suckers.

Subclass Nautiloidea (Tetrabranchiata)

This subclass is characterised by the presence of four ctenidia, four auricles and four kidneys. The shell is external. The example of this subclass is *Nautilus*. The funnel is incomplete and comprises in two lobes called epipodia.

Subclass Ammonoidea

This subclass contains the fossil forms. They possess exogastrically coiled shell. They are probably tetrabranchiate type. The examples are the Ammonites.

GENERAL NOTES ON MOLLUSCS

HISTORY

Molluscs are familiar to man from prehistoric times as the item of food and for their ornamental shells. Extensive work has been carried out by different workers on the molluscan anatomy. Aristotle described many Molluscs, specially the Cephalopods and divided Molluscs into two groups depending on the presence or absence of shell. Jonstonus (1650) coined the term **Mollusca** and his group Mollusca included the barnacles. Linnaeus also retained the term Mollusca and included heterogeneous soft-bodied forms like Tunicates, Anemones, Cephalopods and Polychaetes. Cuvier (1795) threw the modern light on molluscan taxonomy. Lamarck (1815–1819) excluded the Bivalves from this group Mollusca. De Blainville (1825) adopted a new name, **Malacozoa** for the Molluscs. Although this name is no longer retained in modern text books, the term 'Malacology' signifying the science of Molluscs is still in use. The barnacles had long been included under Mollusca, but Thompson (1830) and Burmeister (1834) established their Crustacean affinities and excluded them from Molluscs.

The group Solenogastres established by Gagenbaur (1878) had long been taken as Holothurians, but Graff (1875–1877) studied their molluscan nature and included them under Mollusca. Like Solenogastres, inclusion of Scaphopods under Mollusca had long been a controversial issue. Cuvier and Lamarck placed them with Annelids, but their molluscan organisation was established by Deshayes (1825), Clark (1851) and Keferstein (1862–1886). They also placed the Foraminifers under Mollusca which were ultimately separated by Dujardin. The detailed classificatory scheme of Gastropods after undergoing profound alterations since Cuvier (1795) has attained a sort of stability. The molluscs have been divided into different classes depending upon the nature of respiratory structures. The classification of Molluscs directly into classes—Monoplacophora, Solenogastres, Polyplacophora, Scaphopoda, Bivalvia or Pelecypoda, Gastropoda and Cephalopoda are still accepted in many recent text books. The modern trend in the scheme of classification of phylum Mollusca is to divide them into six classes. The classes are: Monoplacophora (including *Neopilina*), Amphineura (including Solenogastres and Chitons), Scaphopoda (including tooth-shells), Gastropoda (including the single-valved snails), Bivalvia (including the bivalved molluscs) and Cephalopoda (including octopuses, squids etc). But the subdivision under the classes vary greatly.

HABIT AND HABITAT

Molluscs are noted for their adaptive modifications to different modes of life. They are distributed in almost all the parts of the earth and exhibit variety of forms. Besides their abundance in space, they have left behind a continuous palaeontological records since Cambrian period. Majority of the Molluscs are aquatic and a few are adapted to terrestrial environment. Usually the snails and slugs lead a land life. The aquatic Molluscs are mostly marine. Few Bivalves and snails inhabit fresh water or brackish water. They usually

live in the sea shores or in shallow water. Some Molluscs are pelagic and a few are recorded to sink down to the depth of about 35,000 feet. Most of the molluscs are nocturnal.

Greatest number of Molluscs are free-living forms. As regards locomotory power, they range from very slow moving to fast swimming forms. They exhibit variety of modifications. By the modification of foot, they can creep, leap, burrow, float or swim. Some Bivalves fix their bodies on the substratum by the byssus apparatus.

Molluscs are mostly herbivorous and live on available vegetable by scraping with the radular apparatus. Most of the Bivalves live on micro-organisms, but the larval forms for some time lead ectoparasitic life in the gills of fishes. All Cephalopods are predaceous forms and live on small fishes and Crustaceans. The Gastropods have different food habits. They are mostly vegetable feeders and some are predaceous. Amongst the Gastropods, the members of the order--Pyramidellacea lead semiparasitic life, where as that of Parasita includes all endoparasitic forms living in the body of Holothurians.

NUMBER AND SIZE

The phylum Mollusca is noted for its numerical abundance. In this respect Molluscs occupy a position next to Arthropods in the animal kingdom. It is extremely difficult to give an accurate data of the total number of species under the phylum.

Molluscs are remarkable for their range of size and forms. The size varies from 1 mm to 18 m long. This phylum includes the largest invertebrate form known in the world. The following account will give an idea about the different size of molluscs: **Chitons.** The size varies from 1·3 cm to 30 cm. The largest genus is *Amicula* of Pacific coast. **Scaphopods.** The elongated shell is usually 6·5 cm in length but the length may extend up to 15 cm. **Gastropods.** They have usually globose body. The average diameter is less than 5 cm. *Hemifusus proboscifera* has the shell of 60 cm long. *Aplysia california* has the largest body of 1 m in length. **Bivalves.** Usually the size ranges between 1·3 cm to 11·7 cm. The body of *Tridacna gigas* reaches a length of 1·35 m and weighs about 200 kg. **Cephalopods.** Some squids and Octopuses have 2·6 cm long body. The giant squid, *Architeuthis* of north Atlantic has a 18 m long body with the arms.

MANTLE AND MANTLE CAVITY

Presence of mantle is a very distinctive feature of Mollusca. The mantle cavity usually communicates to the exterior and encloses the respiratory organs. The mantle secretes the shelly matter and the edge of the mantle is the active productive center. The mantle cavity is modified in different groups of Molluscs. In Prosbranchia, the mantle cavity is situated on the left side of the body and its anterior portion is prolonged into a tubular siphon. In Pulmonata the mantle fold encloses the pulmonary sac. In Bivalvia mantle cavity is equally developed on either side of the body and the mantle forms a sort of lining to the valves of the shell. Progressive fusion of the edges of the mantle is observed in different bivalves (Fig. 17.54). In *Nucula*, *Arca*, *Trigonia* the mantle edge is perfectly free and the siphons are absent. In *Mytilus*, *Cardita*, *Astarte* the mantle edge is fused at one point in the middle region of the posterior side and forms the rudiment of the 'Branchial siphon'. In *Venus*, *Cardium*. *Lucina* the branchial aperture is divided and the mantle is fused at two places to form three apertures. Through the ventral aperture protrudes the foot. In *Tridacna*, *Chama* the fused area become extended and in *Teredo*, *Pandora* fusion of the mantle edge forms a closed cavity excepting at three openings, one for foot and the other two for the siphons. In some forms, a fourth aperture is present which bears a definite relation to the byssus apparatus. In *Lyonsia* a thick byssus protrudes through this particular opening.

In some Molluscs the mantle may be reflected over the external surface of the shell and subsequently the mantle edge may fuse to make the shell internal. Transitional stages are observed in *Cypraea*, *Marginella*, *Scutus*, where a considerable portion of the shell remains enclosed by mantle. But in *Aplysia*, *Lamellaria* the shell is completely enclosed by mantle. Amongst Pulmonata subsequent transformation from a completely external shell to internal shell is also observed. Indication of such changes is also observed in some Bivalves.

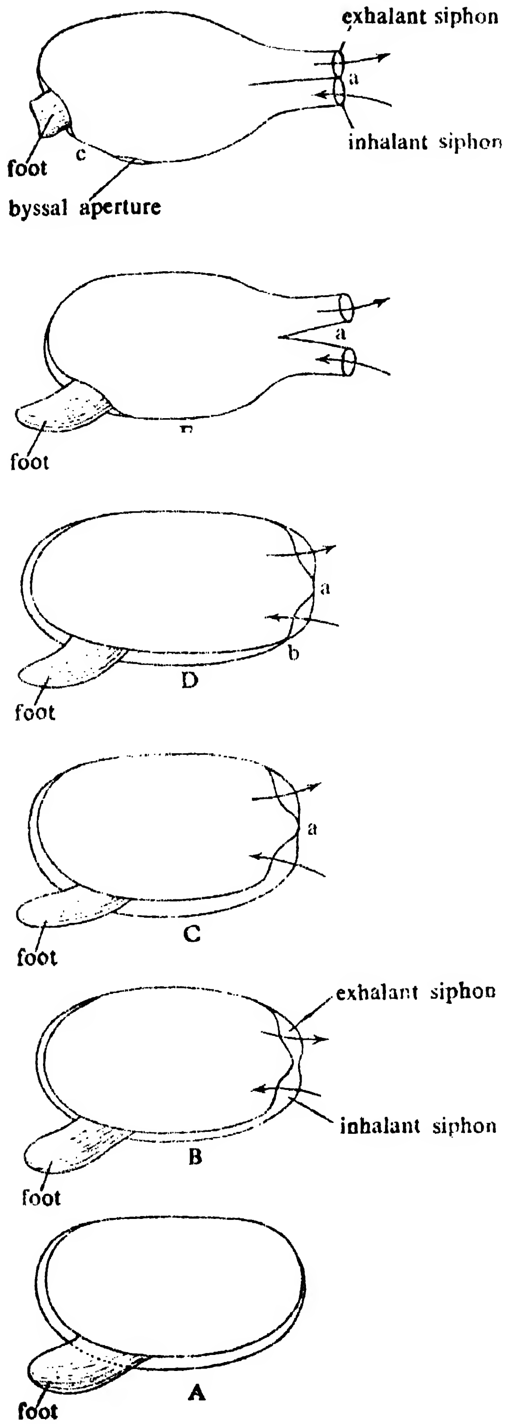


Fig. 17.54. Diagrammatic pictures showing the stages (A–F) of fusion of mantle lobes in different bivalves. *a*=first indication of union of siphons. b=point of fusion between inhalant siphon and foot. c=point of fusion between foot and byssal aperture.

SHELL

The shell is one of the most important diagnostic structures in Molluscs. It has previously been employed as a basis for classification. Like all other structures, the shell also exhibits wide variations in different molluscs. It is present in almost all the members of Mollusca, but varies greatly in disposition. The shell may be present outside the body as in most Gastropods, Bivalves and Chitons. Internal shell occurs in most Cephalopods and in some Gastropods. Transitional stage, where the shell is partly internal and partly external is observed in Hemphillia and Naticidae. In some Cephalopods and Nudibranchia, the shell is absent in adult stage.

TYPES OF SHELL. The majority of molluscs possess univalve shell and the rest may have bivalved shell or may even composed of eight plates as in Chiton.

UNIVALVE SHELL. Normally the univalve shell is an elongated cone which becomes twisted into a spiral round an axis. The shell was originally a simple cone, but due to the increase in size of the visceral hump the shell has become twisted to accommodate whole of the visceral organs. In some cases the shell instead of forming an elongated spire, forms either a flattened spire (*Polygyrantia*) or a globular spire (*Pila*). Amongst cephalopods the shell varies in form. It may be simple as seen in the Squids. In other forms it is usually spiral and chambered. The shell of *Spirula* and the shell of *Nautilus* are typical representatives. In *Spirula*, the shell is spirally twisted but the spirals do not touch and internally it is chambered like that of *Nautilus*. But the relation of the soft parts with reference to the shell differs in *Spirula* and *Nautilus*. The shell in *Spirula* shows *endogastric* curvature but in *Nautilus* it is *exogastric*. In *Spirula* the shell is internally placed and remains covered completely by mantle. The shell of extinct Ammonoidea is more or less similar to that of *Nautilus*. *Octopus* lacks shell excepting a pair of small vestiges. In female *Argonauta* an external thin shell is present (see Fig. 17.52A). It is delicately coiled and is not chambered.

Types of spiral. In different molluscs considerable modifications of the spiral occur. Usually the spire is more or less obliquely coiled round the axis. Two types of spirals are usually encountered in molluscs. They are:

Dextral. In most of the univalve shells, the spiral is dextral meaning thereby that the spiral is right-handed round the axis.

Sinistral. This type of spiral does not occur commonly. This condition is just reverse to the dextral form, i.e. the spiral is left-handed. Occurrence of sinistral type of coiling may be regarded to be normal in certain species and in most cases sinistral type of shell represents abnormal forms. In cases where sinistral monostrosity or in which a sinistral and dextral forms are interchangeable, the internal organs become affected in relation to such coiling. The direction of spiral does not show uniformity in all cases. In some cases, the sinistral type of shell in the embryonic stage is converted into dextral type in adults. Abnormal growth of shell occurs in nature which varies from simple to complex. In some cases the abnormality reaches the peak and may change the entire normal organisation of the creature.

BIVALVE SHELL. This type of shell is the characteristic of the class Bivalvia. Based on the relation of two valves, the shell may be equivalve or inequivalve. The dorsal margin of the two valves are usually united by ligament. The two valves can be opened or closed by adductor muscles. The impressions of the adductor muscles are visible on the inner surface of the valves. The inner surface of the valves shows pallial lines which are actually the impressions produced by the muscular edge of the mantle. The ligament which unites the two valves consists of two parts, the externally located ligament proper and the internal cartilage. In *Pecten* the external ligament is ill-developed and thin. The internal ligament is well-developed and is situated in a shallow pit. The ligament proper is non-elastic and is insoluble in caustic potash, whereas the cartilage is elastic and is soluble in caustic potash. The valves are articulated by a hinge, which in most cases, is furnished with interlocking hinge-teeth. In some Bivalves like *Anodonta* and *Mytilus*, hinge-teeth are absent. The hinge-teeth are derived from the crenulations of the shell surface. The absence of hinge-teeth in *Anodonta* may be the result of secondary degeneration.

COMPOSITION OF SHELL. The main material constituent of the shell is carbonate of lime. Traces of phosphate of lime and an organic base called *Conchiolin* (chemically allied to chitin) are present. In addition, carbonate of magnesium and trace of silica are also detected. *Conchiolin* constitutes a sort of membranous framework for the shell. It is generally regarded that the shell has two parts, the cellular and the membranous parts. Cellular structure is very rare and the membranous part constitutes the sole material basis. The membranous part was once a part of the mantle. Majority of the Gastropods possess porcellaneous shell consisting of three layers, each of which is composed of plates. The orientation of the plates in the three layers has definite regularity. If in the middle layer the plates are transversely arranged then the outer and the inner layers have longitudinally arranged plates. In Bivalves the nature of formation and disposition of layers are similar to that of Gastropods.

FORMATION OF SHELL. Opinions differ as regards the formation of shell. Bowerbank and Carpenter advocate that the formation of shell is an organic process. It grows in the same manner as the teeth and bones of higher organisms. But the modern workers like Reaumur and Eisig hold that the shell is the by-product of excretion and is deposited like the cuticle of Arthropods. Shell is formed by a large number of calcareous particles which are held together by some kind of glue.

The shell is formed from the margin of the mantle. The margin of the mantle is the main source of deposition of shell matter and the rest of the mantle helps to thicken the innermost layer. The shell-depositing cells are present in all parts of the mantle. The carbonate of lime from the circulating blood is separated by the epithelial cells of the mantle edge. The carbonate of lime assumes granular or crystalline forms and becomes hard on exposure. The shell matter in some cases may be deposited by foot also. Deposition of shell matters is not a continuous process but it shows periodicity which is manifested by the *lines of growth.*

Operculum. The operculum is present in almost all marine Prosobranchia. It is a cuticular development on the foot. The operculum exactly fits into the mouth of the shell. In all Opisthobranchia excepting *Acteon* and in all Pulmonata excepting

Amphibola operculum is absent. The shape of the operculum differs in different forms.

FOOT AND ITS MODIFICATIONS

Phylum Mollusca is characterised by the pronounced development of musculature known as the foot. Foot is the locomotory organ in Molluscs. This organ is quite uncommon and strange to others. It is regarded as the remnant of the 'dermo-muscular tube' of the ancestral form whose ventral side became greatly developed as an adaptation for creeping movement and the dorsal portion became degenerated. Typical creeping movement in molluscs, especially in gastropods, is brought about either by muscular activity or by a combination of ciliary and muscular activity. Muscular activity of the foot during creeping movement is effected by a series of wave-like contractions of the longitudinal muscles of foot. The waves of contraction may be *monotaxic* or *ditaxic*. In most of the molluscs the amplitude of waves is small, but in some gastropods as exemplified by *Helminthoglypta dupetithouarsi* the amplitude as well as wavelength are increased during galloping motion. During galloping motion the anterior portion of the foot is elevated and thrust forward (Fig. 17.55). Foot gets the nerve supply from the pedal ganglion. Depending on different modes of locomotion and living in varying environment, the foot in Molluscs varies greatly in shape and form (Fig. 17.56). Variation of foot is primarily due to various physiological activities like creeping or crawling, burrowing, leaping, looping, swimming, reproduction, etc. Besides these, in parasitic and sedentary forms, the modification of foot occurs in the form of sucker, byssus apparatus, etc.

MODIFICATIONS OF FOOT. The primitive and simplest form of foot in Molluscs is considered to be a broad ventral flat sole suited for creeping movement. In most Gastropods, particularly in Prosbranchs the foot becomes differentiated into *propodium*, *mesopodium* and *metapodium* commencing from anterior to backwards and into *epipodium* and *parapodium* from below upwards.

Foot—as the creeping or crawling organ. In *Neomenia* (Fig. 17.56U), a ventral groove with ciliated ridge serves as the locomotory organ. True molluscan foot is absent in this form, but this may be regarded to be the starting point. In Polyplacophora the foot is flat and occupies ventral position. It is very broad in *Chiton* (Fig. 17.56A) and is very narrow in *Chitonellus*. In *Nucula* (Fig. 17.56M) the foot is laterally compressed and directed downward very sharply. In *Anodonta* and *Unio*, the foot is triangular and ploughshare like. Amongst Gastropods, the members of the order Pulmonata possess undivided foot with a very large flat lobe. *Patella* has a well-developed ventral foot with a flat sole to move over the rocks (Fig. 17.56C). The creeping foot may be contractile as in *Triton*. In some cases foot shows partial regional modification. In *Pirulus* only the left part of the foot acts as creeping organ. In *Acteon* (Fig. 17.56K) and *Cypraea* (Fig. 17.56O) foot has a very large creeping sole. They move by producing waves of contraction on the foot. In *Bullia* (Fig. 17.56R) the foot is very peculiar and encircles the whole of the body. In *Natica* (Fig. 17.56D) propodium is demarcated from the rest of the foot by deep transverse grooves as a semicircular flap and the metapodium is provided with lateral parapodia. In *Atlanta*, the posterior part of the creeping foot is altered into a sucker. In *Haliotis*, epipodium is well-developed with many small tentacles (sensory in function). The flat sole of *Murex* (Fig. 17.56S) and the highly glandular foot of *Conus* (Fig. 17.56G) with a long backwardly bent siphon are efficient creeping organs.

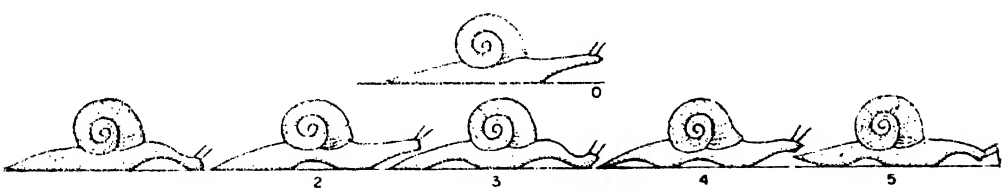


Fig. 17.55. Showing successive events in 'galloping' movements in *Helminthoglypta dupetithouarsi*.

Foot—as the burrowing organ. In some molluscs foot becomes greatly deviated to act as a burrowing organ. In *Dentalium*, the foot is conical and protrusible (Fig. 17.56H). The foot in *Anodonta* and *Unio* also can perform the same

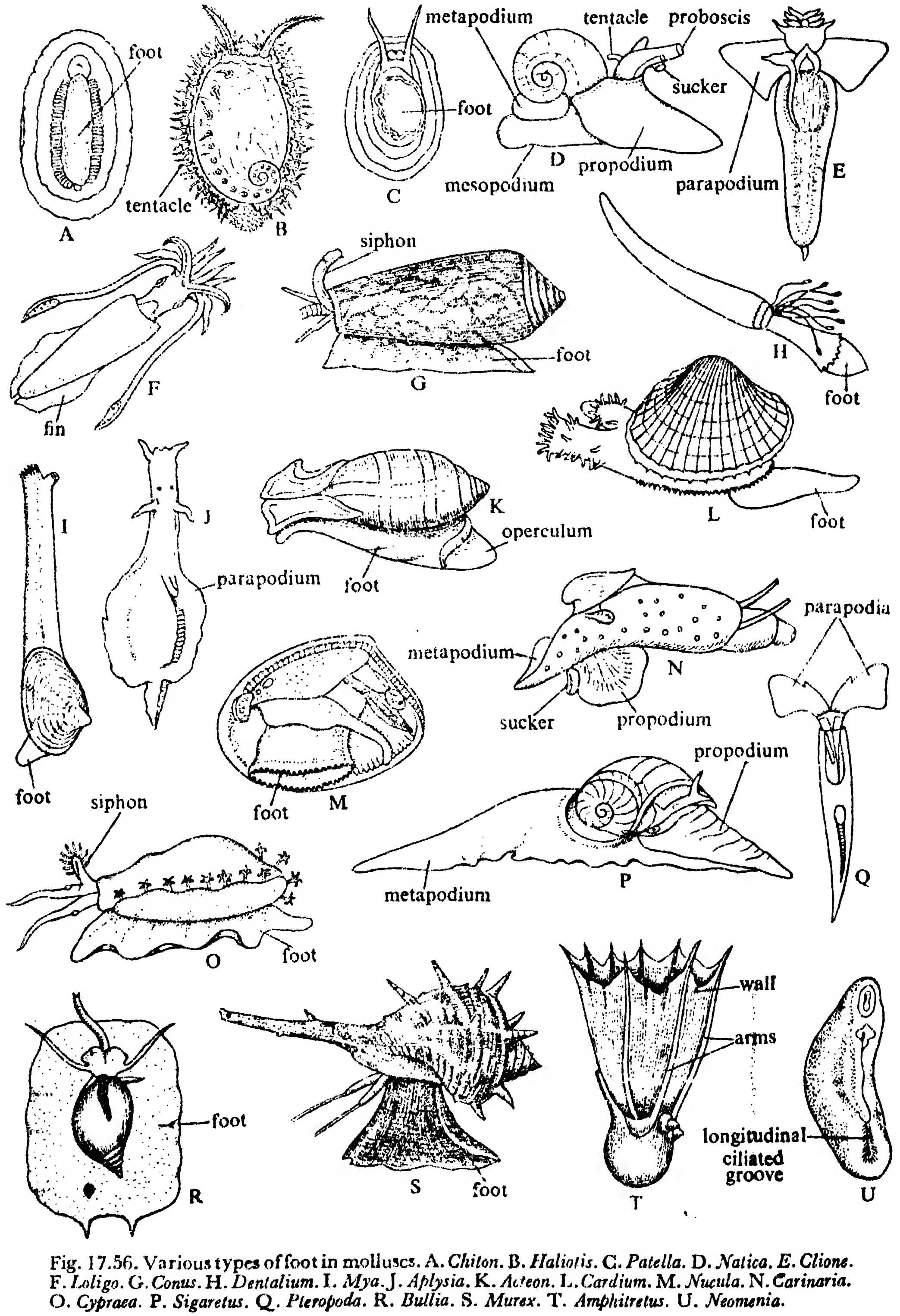


Fig. 17.56. Various types of foot in molluscs. A. *Chiton*. B. *Haliotis*. C. *Patella*. D. *Natica*. E. *Clione*. F. *Loligo*. G. *Conus*. H. *Dentalium*. I. *Mya*. J. *Aplysia*. K. *Acteon*. L. *Cardium*. M. *Nucula*. N. *Carinaria*. O. *Cypraea*. P. *Sigaretus*. Q. *Pteropoda*. R. *Bullia*. S. *Murex*. T. *Amphitretus*. U. *Neomenia*.

function in addition to acting as a creeping organ. In *Sigaretus* (Fig. 17.56P) the propodium is sharply marked off to act as burrowing organ. In *Pholas* foot assumes a short and blunt form. In *Mya* (Fig. 17.56I) the foot is feebly developed and used as a weak burrowing organ.

Foot—as the leaping organ. This type of modification is very characteristic in certain forms of Molluscs. In *Cardium* (Fig. 17.56L), the foot is bent upon itself as a leaping organ. In *Trigonia* it is compressed antero-posteriorly as an elongated keel. In *Poromya*, the foot is curved with well-formed protractor and retractor muscles. In *Mytilus*, the cylindrical foot acts as spring-tail (see Fig. 8.11F). A median triangular outgrowth in *Birabia* acts as leaping organ.

Foot—as a looping organ. In *Pedipus*, the propodium of the foot is sharply marked off from the rest by a groove and helps in looping movement.

Foot—as the swimming organ. In many Molluscs the foot becomes variously modified to swim in water. The development of parapodia is observed in many forms. *Carinaria* (Fig. 17.56N) swims by a flat ventral fin which bears a small sucker representing the original foot. The parapodia is fan-like in *Aplysia* (Fig. 17.56J). The parapodia may have wing-like processes as in *Pteropoda* (Fig. 17.56Q). In *Oxygurus* the parapodia are hollow and possess fin-like outgrowth. In *Atlanta*, the metapodium is produced into laterally flattened swimming lobe. In *Clione* (Fig. 17.56E) the parapodia are well-developed and are placed on the lateral sides of the anterior end. The most notable transformation of the foot as swimming organ is observed in Cephalopods. The oral arms in Cephalopods are the modified forms of a portion of foot. The number of the oral arms varies in different forms. They are eight in *Octopus* (see Fig. 8.11B) and are ten in *Sepia* and *Loligo*. In *Amphitretus* the arms are united by web (Fig. 17.56T).

Foot—as an organ helping reproduction. In some Cephalopods, during breeding season arms become hectocotylised in males which act as intromittent organ.

Accessory glands associated with the foot. The foot in Molluscs is also a highly glandular structure. Some glands become intimately associated with the foot to help in locomotion. The secretion of the glands lubricate the passage during movement. In Gastropods the pedal glands and the unpaired sole gland are the typical instances. In some Bivalves, in adult or in larval stages the byssus apparatus helps in the process of adhesion. The *Organ of Valenciennes* in some Cephalopod females, *Van der Hoeven* in *Nautilus* males are the other notable accessory organs associated with the foot.

The above discussion reveals a strong variation with regard to functional and structural modifications of foot in different forms of Mollusca. Variation in the mode of progression in different forms of Molluscs is the primary cause of variation of foot. In all forms of Molluscs foot becomes very much swelled during locomotion. What causes such swelling is not clearly understood. It is probable that the swelling is caused by the flow of blood into foot which is prevented from returning to the body by sphincter muscle.

RESPIRATORY ORGAN AND MODIFICATIONS

The members of the phylum Mollusca show different modes of living. Some of them are aquatic, some are terrestrial and others are amphibious in their habitats. As a consequence of living in diverse environmental conditions, the respiratory organs are modified accordingly. The respiratory organs encountered in Molluscs are mainly the ctenidia and the lungs or pulmonary sac. The outer covering of the body and mantle usually act as accessory respiratory organs.

Skin—as respiratory organ. Skin appears to be the simplest type of respiratory structure encountered in Molluscs. It acts as a respiratory organ in certain forms where there is no special respiratory device. Such type of respiratory organ is found in *Cenia*, *Limapontia*, parasitic *Entoconcha*, etc. In most of the members of Aeolididae the dorsal surface of the body is provided with papillae. The papillae are variable in size and communicate with the heart by veins. Most of the Nudibranchia respire through skin.

Ctenidium—as the respiratory organ. Majority of the molluscs respire through ctenidium. A typical ctenidium has an axis having afferent and efferent blood vessels

and a row of flattened gill filaments on each side of the axis. Based on the topography, the ctenidia present in Molluscs can be divided into the following categories:

Holobranchiate type. This type of arrangement of ctenidia is found in Polyplacophora. In this form the ctenidia extend all over the body. The number of ctenidia varies from fourteen to seventy pairs and in some cases the number may be about eighty pairs as in *Acanthopleura*. In *Patella* a circlet of gill lamellae extends completely around the margin of the mantle. It resembles that of *Chiton* superficially which made Cuvier to include *Patella* and Chitons under one class Cyclobranchia. But the true nature of ctenidia differs greatly. In *Chiton* the ctenidia are present along the margin of the body excepting the head and anus, but in *Patella* the ctenidia are extended throughout the body.

Merobranchiate type. When the ctenidia remain restricted to a particular area of the body it is called the merobranchiate type. The merobranchiate type of ctenidia can be subdivided into the following types depending on the arrangement of leaflets.

Plicate type. This type of gill comprises in simple flat transversely folded projecting integumentary laminae. In *Neomenia* a tuft of filaments arises from the cloacal wall.

Monopectinate type. This type of ctenidia consists of flattened gill filaments arranged in a single row as observed in *Pila*, *Triton*.

Bipectinate type. This type of ctenidium has flattened gill filaments arranged in two rows. They may be of two types:

Unequal. When both of them are present, but right one is smaller as observed in *Fissurela*, *Haliotis*.

Equal. When both of them are of same sizes. This is the characteristic of the bivalves. Amongst Bivalves they become variously modified (Fig. 17.57). *Nucula* possesses short flat leaflets (Fig. 17.57A). In some forms long filamentous leaflets are present. These filaments may be free as in *Arca* (Fig. 17.57B, C) or may be joined by ciliary connectives as in *Mytilus* (Fig. 17.57D). In *Unio* (Fig. 17.57E) the ciliary junctions are replaced by membrane.

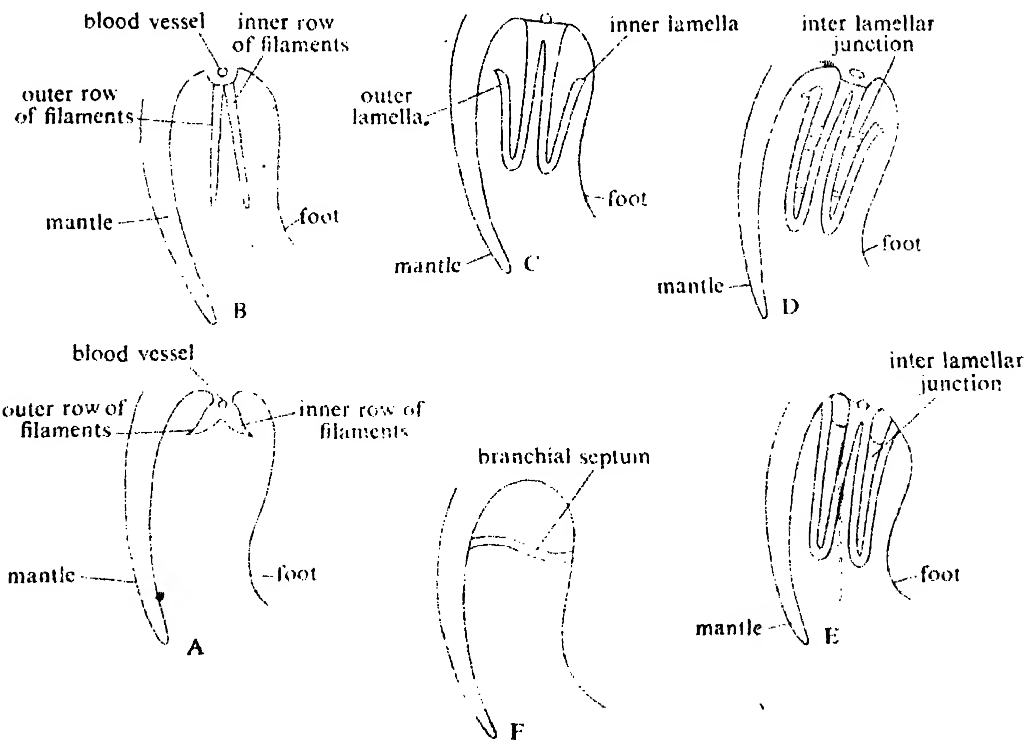


Fig. 17.57. Transverse sections showing the arrangement of gills in bivalves. A. *Nucula*, B. *Amasium*. C. *Arca*. D. *Mytilus*. E. *Unio*. F. *Poromya*.

In *Poromya* (Fig. 17.57F) the ctenidium becomes degenerated and is represented as a transverse partition.

Feathered type. This type of ctenidium is characteristic of the Cephalopods. Detailed structure is described in the biology of *Sepia*.

Modifications. The ctenidia become modified in some forms.

Anal gills. In *Doris* (see Fig. 17.48B) delicate leaflets form a rosette round the anus and is designated as the *anal gills*. In Pterotrachea the mantle fold is absent and the filamentous branchial leaflets project freely and remain uncovered. In most cases the mantle may serve as respiratory organ. In Solenogastres the *cloacal gills* are present. Gradual degradation of the cloacal gills is encountered. In *Chaetoderma* the gills are two in number and are symmetrically placed one on each side of the cloaca. Single distinct gill is present in *Neomenia* and in *Proneomenia*, the gills are nothing but a few folds on the cloacal wall.

Cerata. In *Aeolis* many highly vascular secondary gills (*Cerata*) are present on the dorsal surface of the body (see Fig. 17.48C).

Relationship between heart and gills. The heart and the gills are intimately related because the main function of the gills is to aerate blood on its way to the heart. The number of gills are directly proportional to the number of the auricles (Fig. 17.58). For example, when the gills are two in number, two auricles are present as encountered in *Octopus* and *Loligo*. In *Chiton* two auricles correspond to the two sets of the multiple gills. In *Nautilus* there are four gills and four auricles. When the gill is unpaired, the heart has one auricle as seen in Opisthobranchs, Rachiglossa, Taenioglossa, etc.

Respiratory organs for terrestrial mode of living

Terrestrial habit leads to complete loss of gills and a variety of respiratory organs develop to suit the particular environment. They are as follows:

Pulmonary sac. In most Pulmonata the mantle cavity forms a pulmonary chamber, the inner surface of which is highly vascularised.

Trachea. In some Pulmonata, the pulmonary chamber gives off breathing air-tubes called trachea.

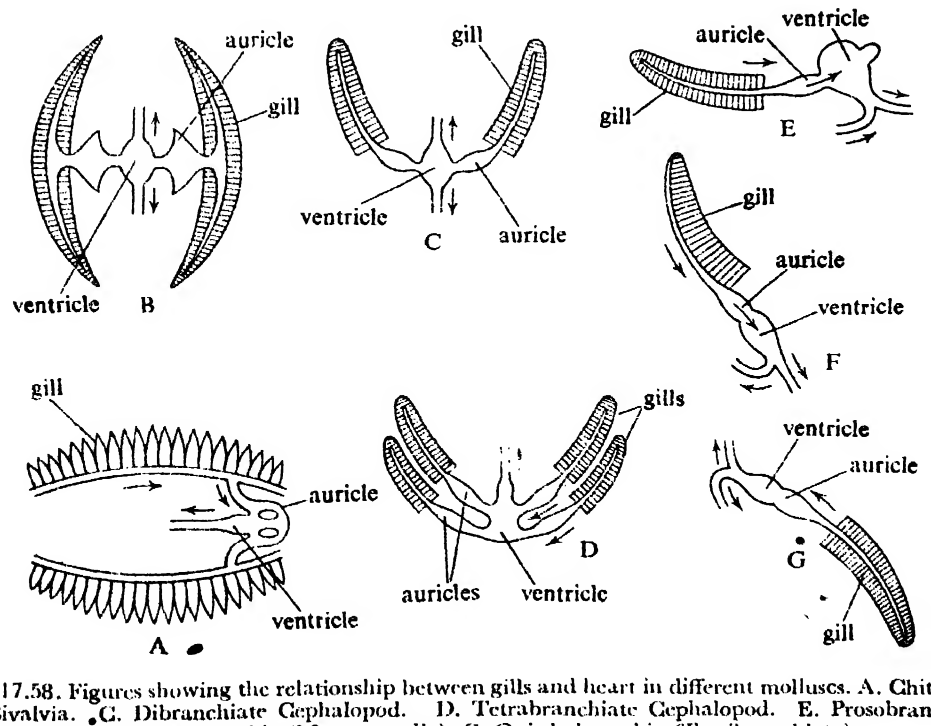


Fig. 17.58. Figures showing the relationship between gills and heart in different molluscs. A. Chitons. B. Bivalvia. C. Dibranchiate Cephalopod. D. Tetrabranchiate Cephalopod. E. Prosobranchia (Diatocardia). F. Prosobranchia (Monotocardia). G. Opisthobranchia (Tectibranchiata).

Nuchal lobe. In Monotocardia the left nuchal lobe is better developed and forms a long respiratory siphon.

Amphibious forms. These forms are exemplified by *Pila.* It possesses both ctenidium as well as pulmonary sac. The genus *Siphonaria* is furnished with a lung-cavity and a ctenidium. Both the forms represent a transitional stage between aquatic and terrestrial life.

CIRCULATORY SYSTEM

The circulatory system in Molluscs is quite well-developed. Almost all the members of the phylum (excepting *Scaphopoda* which lacks a distinct heart) have distinct heart which receives oxygenated blood from the respiratory organs and conveys it to the different parts of the body.

Blood. The blood in Molluscs is colourless. The respiratory pigment is haemocyanin, which contains both iron and copper. Haemoglobin is also present in some rare cases, e.g. *Planorbis.* Special blood corpuscles with haemoglobin are present in *Solen legumen, Arca noae.*

Heart. The heart is composed of muscular ventricle and thin-walled auricle. The auricle gives origin to aorta which in turn divides into arteries to supply the various parts of the body. Blood from the different parts of the body is returned to the respiratory organs. After oxygenation blood is returned to the heart from the respiratory organs to complete the circuit. The ventricle is usually single, but the number of auricle varies from one to four. The number of auricle corresponds to the number of ctenidia present. Majority of the Molluscs possess one auricle. Double auricles are present in Chitons, Dibranchiate Cephalopods and Bivalves. Tetrabranchiate Cephalopods possess four auricles. The number of aortae originating from the ventricle vary from one to two. Single aorta is present in Chitons, Solenogastres, Prosobranchia, etc. In some forms there are two aortae leading out of the two ends of the ventricle. In most Gastropods, a single aorta bifurcates into an anterior cephalic aorta and a posterior visceral aorta. The topography of heart also shows variation. The heart is placed within the pericardium. In bilaterally symmetrical forms the heart lies on the median line of the body, while in asymmetrical forms the heart is shifted to one side of the body, usually on the right side.

Course of circulation. In Molluscs the blood from the ventricle is carried through aorta/aortae into the arteries. The arteries supply blood to the different parts of the body. After making an excursion through the different organ systems, the blood is collected into irregular spaces—the *lacunae* which in turn open into *sinuses.* Existence of capillaries is said to occur in Dibranchiate Cephalopods and in some Bivalves. The relationship between the foot-pore and the circulatory system in some Molluscs has not yet been fully established. In the opinion of many workers these foot-pores help the incoming of water into the circulatory system.

NERVOUS SYSTEM

The nervous system in Molluscs (Figs. 17.59–17.61) presents numerous diversities. It exhibits gradual coming up of complexities from simple to complex which can be marshalled into one perspective—the nervous co-ordination. Prior to the description of the nervous system in different forms of Molluscs a basic plan of the Molluscan nervous system is to be considered first.

Hypothetical plan of molluscan nervous system. The central nervous system consists of three pairs of ganglia, the cerebral, pedal and pleural ganglia. These ganglia are connected by connectives and commissures. The connectives are the cerebro-pedal, cerebro-pleural and pleuro-pedal. The commissures are present between the cerebral, pedals and the pleurals. The peripheral nervous system comprises in a pair of visceral ganglia connected by commissures. Another pair of parietal ganglia are connected with this system.

Comparative account of nervous system in different forms. From this basic scheme, wide range of modifications has taken place. Concentration of the whole system, attainment of deeper mode of nervous co-ordination, attainment of complexities due to torsion, detorsions and abortion or exaggeration of some parts are the main causative factors.

Protoneurous condition. This condition of nervous system more or less resembles the hypothetical type. This condition shows a gradation of complexities. It may

be of undifferentiated type as seen in *Chiton* where the nervous system is without any definite ganglionic formation (Fig. 17.59G). It may be differentiated type where definite ganglionic formation is observed. The formation of ganglia shows gradual sequence of modification and evolution. In Solenogastres the nervous system is ladder-like and the cerebral ganglion is single (Fig. 17.59D), but in

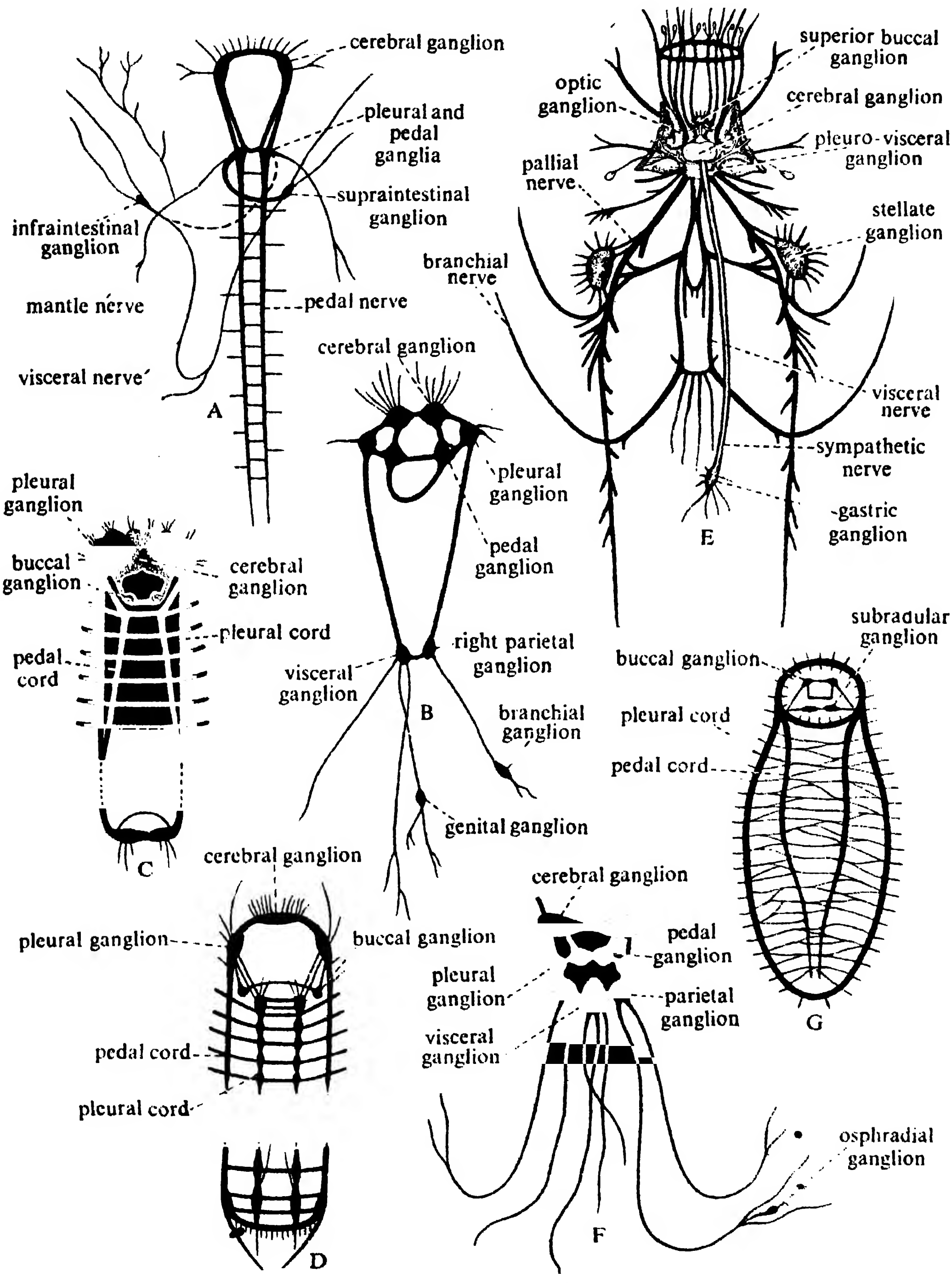


Fig. 17.59. Nervous system in Molluscs. A. *Haliotis*. B. *Aplysia*. C. *Chaetoderma*. D. *Neomenia*. E. *Sepia* F. *Limnaea*. G. *Chiton*.

Chaetoderma it becomes double (Fig. 17.59 C). In Scaphopoda, the nervous system is symmetrical. The pleuro-pedal connectives become fused with the cerebro-pedal connective. There is no distinct parietal ganglion. In *Unio* the parietal ganglia are fused with the visceral ganglion and thus forming the viscero-parietal ganglion (see Fig. 17.14).

Streptoneurous condition. This particular condition of the nervous system is observed in Gastropods, particularly in Prosobranchs. Lateral twisting of the nervous system occurs with reference to the torsion of the whole pallial complex. The original parietal ganglia are renamed according to their new positions. When the parietal ganglion is situated above the level of the oesophagus, it is called *supraintestinal ganglion* and when it is located below the level of the oesophagus the ganglion is designated as *infraintestinal ganglion*. The *pleuro-visceral connectives* are crossed and assume a pattern like the figure-of-8. The whole of the nervous system assumes secondary asymmetry. Such a condition in the nervous system in Molluscs is called the *Streptoneury*. The streptoneurous condition in different Gastropods exhibits gradation of diversifications and complexities.

Simple chiastoneury. This condition is observed in *Cyclostoma elegans*, *Atlanta*, *Chilina*, *Planorbarius* and in many other Gastropods. In these forms the parietal ganglia are replaced by supraintestinal on the left and the infraintestinal on the right side of the body. The pleuro-visceral connectives are interrupted, the original right and left connectives cross each other. In *Pila* (see Fig. 17.24), the chiastoneury is diffused because of the fusion of the infraintestinal ganglion with right pleuro-pedal ganglionic mass. The original infraintestinal nerve still persists as an evidence of migration and fusion of infraintestinal ganglion.

Complicated chiastoneury. In most Gastropods the circumenteric nerve ring remains more or less the same excepting the tendencies towards shortening of the nerves between the ganglia. In *Janthina* (Fig. 17.60B) the nerves between the ganglia of the circumenteric nerve ring are quite elongated and the ganglia are quite set apart. The pleural ganglia give off *pallial nerves* to the mantle. In many cases like *Patella* (Fig. 17.60D), Cyclophoridae, a *circumpallial nerve* joins the two pallial nerves to form a complete nerve ring. The pleuro-visceral loop, in most Gastropods, crosses each other to maintain streptoneurous condition. This pleuro-visceral loop exhibits great variation amongst different Gastropods. A very common tendency is the gradual shortening of the nerves between the pleural and the intestinal ganglia (*pleuro-intestinal connectives*). In many cases, the shortening of the pleuro-intestinal nerves is so severe that the intestinal ganglia become fused with the corresponding pleural ganglia of the side. In this way the original crossing of the pleuro-visceral nerves is obliterated and only the uncrossed portion of the pleuro-visceral loop remains. In *Patella* (Fig. 17.60D) the pleuro-visceral loop is greatly reduced and is displaced to the right side. The intestinal ganglia are indistinct. The gills and osphradia receive nerves from the pleuro-visceral loop and the intestinal ganglia. Usually these nerves unite with pallial nerves from the pleural ganglia. Such connective adds more complication to the nervous system. To discuss briefly minor variations in Gastropodan nervous system the following points can be cited:

1. The visceral ganglion is accompanied by additional one or two ganglia as seen in an olivid.

2. The pedal ganglia are usually the largest ganglia in the circumenteric nerve ring. They are connected by a commissure of variable length. In *Haliotis* (Fig. 17.59A), *Patella* (Fig. 17.60D) and Pleurotomaria, the pedal ganglia give origin to two elongated pedal nerve cords posteriorly. These two nerve cords are connected by numerous transverse nerves.

3. In *Haliotis*, distinct intestinal and pleural ganglia are absent. A pair of branchial ganglia is connected with the pleuro-visceral nerve cords by short nerve on the corresponding side.

4. In *Fissurella*, the right branchial ganglion is connected to the infraintestinal ganglion and the left one is connected with the supraintestinal ganglion.

Chiastoneury with Zygoneury. In some Diatocardia, there exists connection between the pallial nerves from the pleural ganglion and the nerve from the intestinal ganglia into the mantle. This type of

secondary pleurointestinal connection is regarded as *Zygoneury*. The Zygoneurous condition occurs in *Trochus*, *Triton* (Fig. 17.60A), *Haliotis* (Fig. 17.59A) on the left side. Such connection on the right side also exists in some forms.

Chiastoneury with Dialyneury. In *Janthina* (Fig. 17.60B), *Cassidaria*, *Littorina*, Zygoneury is present on both the sides. Such a condition is called the *Dialyneury*.

Ethyneurous condition. Amongst the Gastropods, particularly in many Opisthobranchs and Pulmonates, the nervous system becomes secondarily symmetrical from the primarily asymmetrical stage. In the lower Opisthobranchs and in Pulmonates, the streptoneurous condition

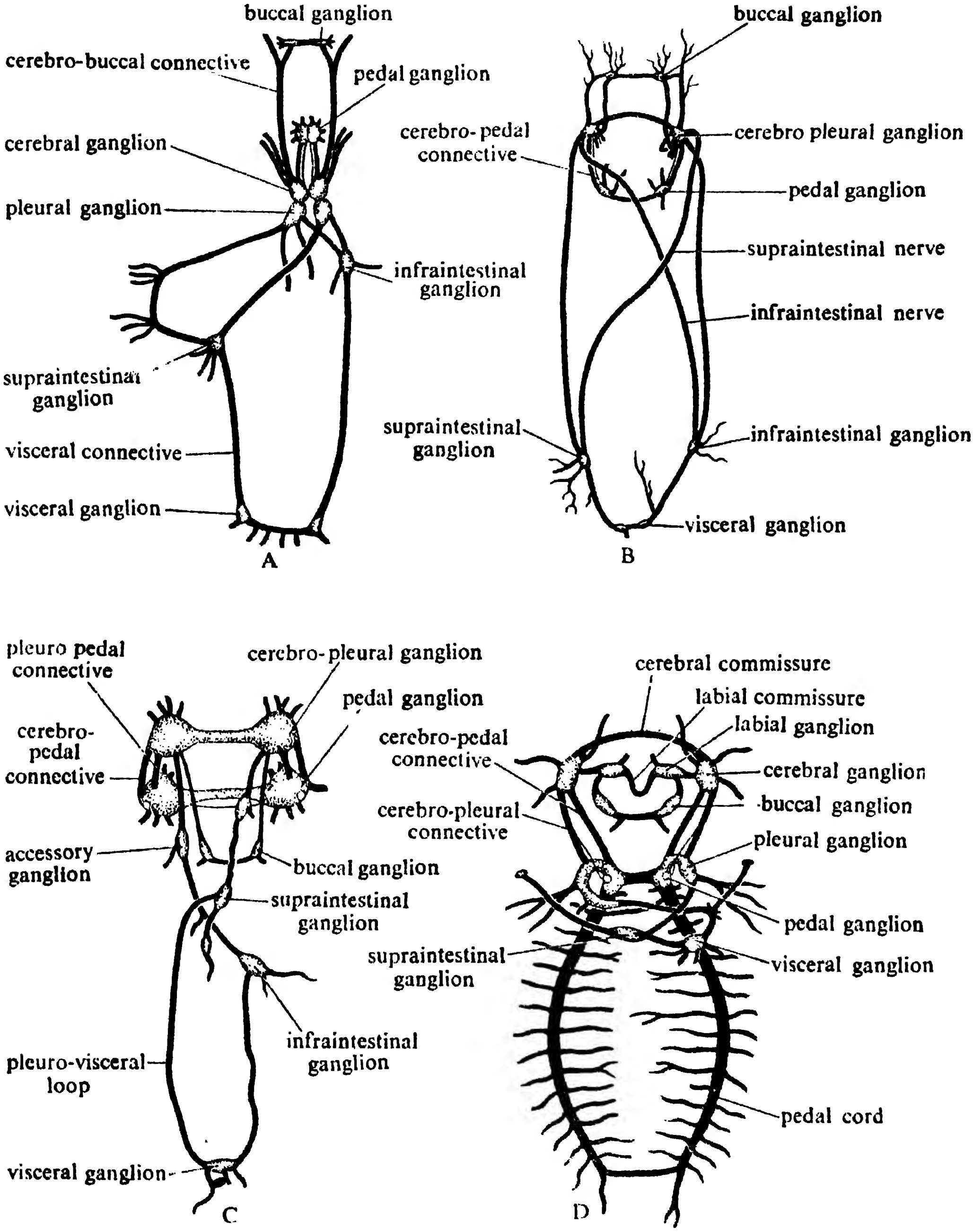


Fig. 17.60. Nervous systems in molluscs (contd.). A. *Triton*. B. *Janthina*. C. *Acteon*. D. *Patella*.

persists but in higher forms secondary symmetry is more pronounced. Attainment of secondary symmetry in the nervous system of these forms leads to a condition called *Ethyneurous* condition. The ethyneurous condition is the result of either detortion or double torsions. A survey of the nervous system in Opisthobranchs and Pulmonates will give the stages of transformation of streptoneurous to the ethyneurous condition.

In *Acteon*, an Opisthobranch and in *Chilina*, a pulmonate, the nervous system exhibits typical streptoneurous conditions by showing usual crossing of the pleurovisceral connectives. Figure 17.60C will give the idea of nervous system in *Acteon*. Another tendency noticed is the anterior concentration of the different ganglia by shortening the commissures and connectives. In *Gastropteron* (Fig. 17.61) the nervous system is a detorted type, where the

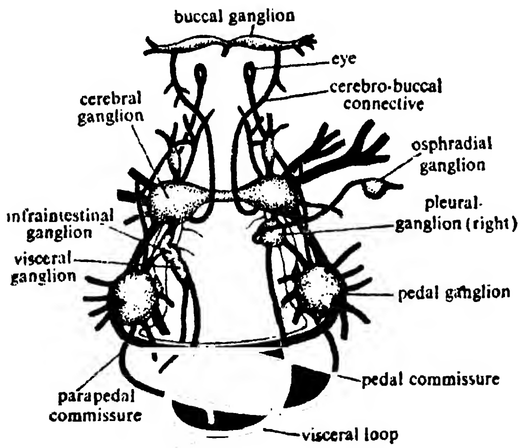


Fig. 17.61. Nervous system in *Gastropteron*.

supraintestinal ganglion has moved to become fused with the right pleural ganglion. The infraintestinal ganglion is similarly fused with the left pleural ganglion. In *Aplysia* (Fig. 17.59B) the nervous system is secondarily symmetrical, but the different ganglia on the circumenteric nerve ring are well-separated. The pleuro-visceral connectives come straight to the posterior side to join the infraintestinal and supraintestinal ganglia about the level of the stomach. In *Limnaea* (Fig. 17.59F) the nervous system is detorted type which is caused by the anterior migration of intestinal and visceral ganglia to become fused with the pleural ganglia.

Cephalopod grade. In Cephalopods the nervous system is usually symmetrical and highly developed (Fig. 17.59E). In Cephalopods higher grade of concentration of the central nervous system and the formation of 'brain' enclosed by cranial cartilage is observed.

Origin of chiastoneury. In the anatomical organisation of Gastropods the pallial complex has changed its position and has become shifted gradually forward along the right mantle furrow (Fig. 17.62 A–D). Each ctenidium becomes shifted along with its parietal ganglion. As long as the pallial complex is not moved far forward to the right the pleuro-visceral connective would not cross but only be shifted to the right as observed in Tectibranchia. Pallial complex is further shifted forward along the mantle furrow till they come to lie quite anteriorly. The original left ctenidium comes to lie on the right and the original right ctenidium dragged its parietal ganglion over the intestine to the left side as the supra-intestinal ganglion. The original left ctenidium has also drawn its parietal ganglion below the level of the intestine to the right side as the infraintestinal ganglion. The pleuro-visceral connectives in which these ganglia lie now cross and give rise to a condition that is designated as *chiastoneury*.

TORSION AND DETORSION IN GASTROPODA

Asymmetrical configuration is a very important feature to note in majority of the Gastropods. Asymmetry may arise prior to the formation of the anus and the mantle cavity. In this case the visceral sac is more developed in the left side, the anus and the mantle cavity appears on the right side. Then the relative growth of the different parts causes migration of the anus and the mantle cavity along the right side until they occupy the anterior end of the visceral sac. In cases where asymmetry is acquired after the formation of anus, the anus and the mantle cavity are present at the posterior end of the body and occupy a median position. These subsequently shift round to the right side and are placed at the anterior face of visceral sac. This shifting is accompanied by the greater development of visceral sac on the left side. This movement comprises in a twisting of the

visceral sac about an axis through an angle of 180°. By this way the original posterior end of the visceral sac becomes the anterior end. The visceral organs of the original right side occupy the left side and *vice versa*. This shifting not only includes the torsion of the visceral cavity round a dorso-ventral axis along the direction opposite to the hands of watch but also the twisting is round a horizontal axis like the spiral from the right to the left side.

The coiling may be *exogastric*, when the torsion makes the visceral cavity forward or *endogastric* when torsion makes the anterior face of the visceral cavity posterior. A survey of the diagrams (see Fig. 17.62 A–D) reveals the subsequent stages of torsion of the visceral mass which causes the twisting of the visceral commissure in the form of a loop like the figure-of-8. Disappearance of organs from the left side of most Gastropods and acquisition of asymmetry are due to torsion.

Acquisition of secondary symmetry observed in some Gastropods is regarded as the result of detorsion. The detorsion means the reversion to the changes that have occurred during torsion. Shifting back of the pallial complex towards the posterior side results in the re-establishment of a secondary symmetry. Different gradations of detorsion are encountered in the different members of Euthyneura. In *Acteon* and *Bulla* detorsion is partial and complex detorsion is observed in *Aplysia*.

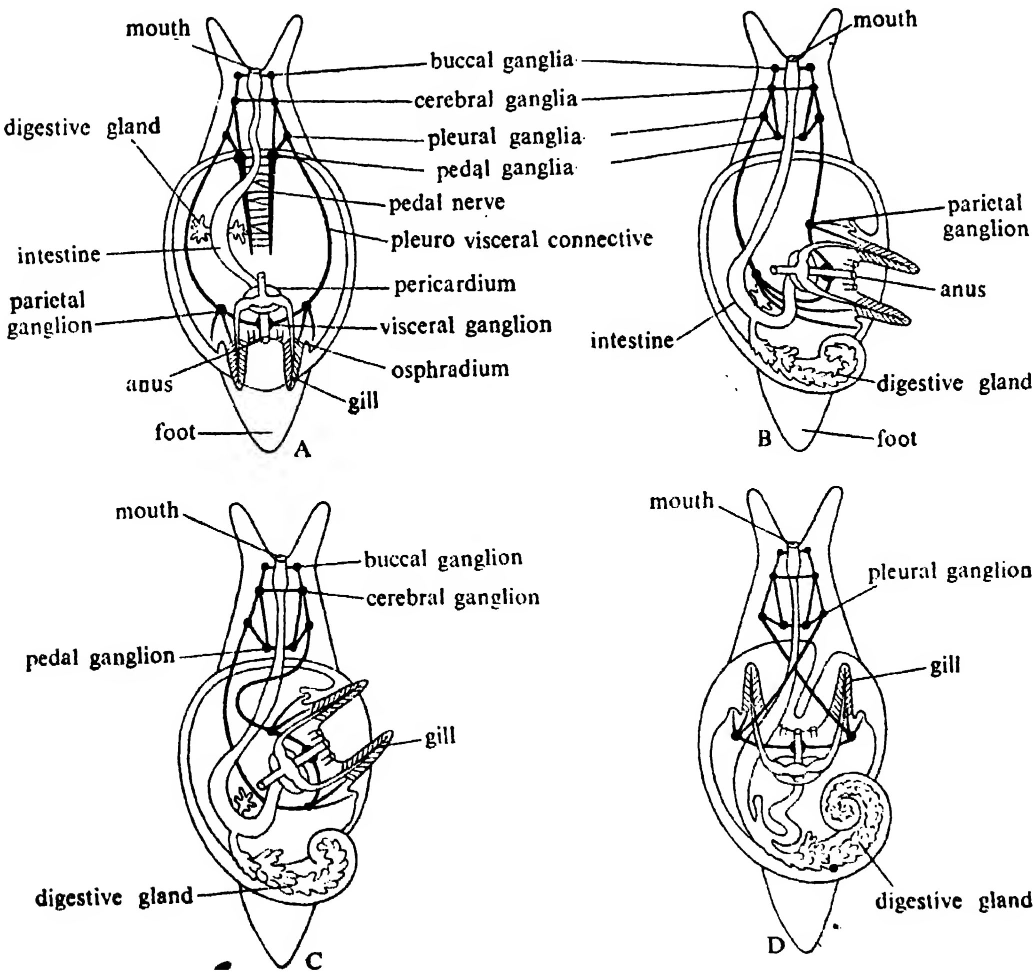


Fig. 17.62. Diagrammatic representation of torsion in Gastropod. A. Hypothetical ancestral stage with symmetrical arrangement of structures. B. Displacement of the mantle cavity to the right side. C. Showing 90° torsion. D. Showing complete torsion.

Visceropallial asymmetry in Gastropoda

The body of gastropod is basically consists of head, a broad muscular foot and visceropallium enclosed in a single piece of shell. Anteriorly the head and foot retain bilateral symmetry. But the visceropallium is asymmetrical. Asymmetry of visceropallium is a fundamental feature in gastropods. This is due to (i) *torsion* and (ii) *coiling* during ontogenic development. Torsion is an event in larval stage, while coiling occurs in post-larval development.

Torsion. Torsion is a feature in larval gastropods. In larval phase of development the visceropallial mass becomes rotated anti-clockwise through 180° from its initial location on the head-foot complex. Contraction of the larval retractor muscles and differential growth are possibly responsible for such rotation. Entire rotation results within few minutes. Asymmetry is encountered at the early stage in Veliger larva where the mesodermal bands develop asymmetrically. The mesodermal band on the right side is larger than its left counterpart. The right band is composed of five mesoderm cells which elongate to form muscle cells. With the transformation of the muscle cells the visceral hump is displaced to the left side. These cells on the right side converge and transform into the larval retractor muscles. The muscle cells are absent on the left side. Torsion of the visceral hump commences as soon as the larval muscle cells attain the power of contraction (Fig. 17.63). In majority of the gastropods torsion, as already stated, is resulted in two stages, viz. Stage-I and Stage-II.

Stage-I. The contraction of the larval retractor muscles account for 90° of the rotation of the visceral hump. This process usually lasts for only a few hours. At the end of Stage-I, the mantle cavity (which was initially situated ventrally and posteriorly) comes on the right side with the foot projecting on the left side.

Stage-II. The rest of the torsion is the result of differential growth and is usually longer in duration. Actual mechanism of torsion in gastropods is not properly known and it is difficult to give a generalised account of torsion in gastropods. However, Thomson (1958) distinguished five possible ways by which torsion has resulted in gastropods. They are:

(a) 180° rotation of visceral hump is achieved by muscular contraction alone. This mechanism is seen in *Acmaea* and is regarded to be the original way of torsion.

(b) The commonest way of torsion (180°) as encountered in *Haliotis*, *Patella*, etc., is achieved in two subsequent stages: (i) the initial 90° rotation is caused by the contraction of the larval retractor muscle and (ii) the remaining 90° is effected by differential growth. The first phase occurs at a faster rate, while the next phase is slower.

(c) In some gastropods as exemplified by *Vivipara*, complete (180°) rotation is achieved exclusively by growth processes.

(d) In *Aplysia*, torsion is resulted by differential growth and the change in position of anus is halted at a region appropriate to the adult stage.

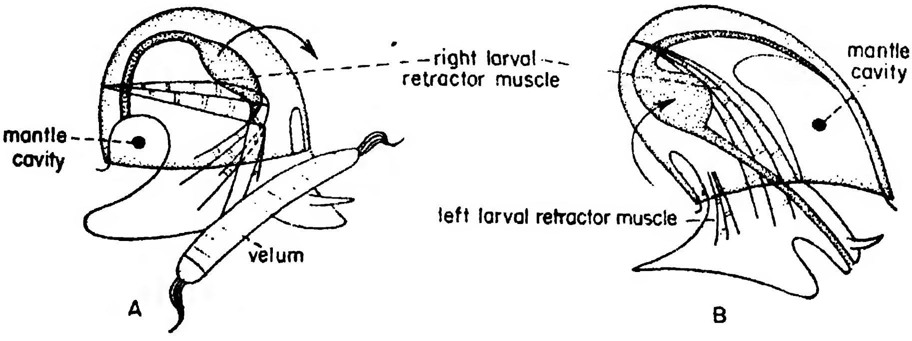


Fig. 17.63. Diagrammatic representation of torsion in veliger larva of a prosobranch. A. Pre-torsional stage. B. Post-torsional stage (after Parker and Haswell).

(e) In *Adalaria*, torsion of the viscero-pallium is not recognisable. The different organs appear as in the post-torsional position.

Whatever be the cause of torsion in gastropods, a post-torsional larva possesses an anteriorly placed mantle cavity and all the developing organs are severely affected. With the completion of torsion many organ systems (e.g. Pallial organs, nervous system) become greatly affected. Formation of loop and crossing of pleuro-parietal connectives are a common occurrence in the nervous system in gastropods, especially protobranchia.

Views on the significance of Torsion in Gastropods

Torsion is a characteristic feature of gastropods. The significance of such torsion in gastropods is not clear. Two contrasting views extant on this issue. They are:

(a) *Garstang's view*: Garstang (1928) advocated that torsion is an adaptive feature and is useful to the larva for protection against enemies. The placement of mantle cavity at the anterior end in the larva gives greater protection of the head and associated structures. The mantle cavity provides a protected space for the withdrawal of the foot and head in case of danger.

(b) *Morton's view*: Morton (1958) emphasises the importance of anterior location of mantle cavity both in larval and adult molluscs. The anteriorly placed mantle cavity housing the head with sense organs, respiratory structures, etc. in adult add positive advantage to test the water and also to come in intimate contact for gaseous exchange with the oncoming water respectively.

Coiling. The ability of withdrawal of the head-foot complex into the anterior mantle cavity due to torsion increases the efficiency in locomotion, feeding and sensory function in gastropods. The head-foot complex retains its bilateral symmetry. The visceral hump together with the protecting shell becomes coiled to economise the volume.

EXCRETORY SYSTEM

In Molluscs the excretory system comprises of the *kidneys* and the *pericardial gland.* Each kidney is a special portion of the coelom and remains in communication with other parts of the coelom. The glandular tissue of the kidneys is arranged in various ways in different forms. The kidneys are usually paired, symmetrical and coiled structures. The kidneys are dorsally placed near the pericardium. One end of the kidney opens externally into the mantle cavity while the other end opens internally into the pericardium by the *reno-pericardial aperture*.

Besides kidneys, there is special glandular tissue in the pericardial or viscero-pericardial division of the coelom. This tissue constitutes the pericardial gland.

Kidneys. The kidneys in molluscs represent the special portion of the coelom. In all the Molluscs excepting *Nautilus*, the kidneys communicate with the coelom. The most primitive and typical condition of the excretory system of Molluscs are observed in Chiton. The kidneys consist of two symmetrical glandular structures on the dorsal part of the body and are located near the pericardium. Each kidney communicates to the mantle cavity by one end near the anus and the other end opens into the pericardial cavity by *reno-pericardial aperture*. The arrangements of the glandular tissue in the excretory organs vary greatly in different forms of Molluscs. The number of the kidney in different Molluscs depends upon the number of auricles and ctenidia.

The epithelial lining of the pericardium usually contains glandular tissue and constitutes the **pericardial gland.** In some cases the glandular tissue may also be present in the auricular wall.

Kidneys in different Molluscs vary greatly. In Bivalves the kidneys are two in number. They may assume the form of twisted tubes which may be dilated at certain regions. The reno-pericardial aperture is usually lined by an yellowish glandular tissue which can also extract the excretory products directly from the blood. In a few Bivalves the two kidneys are in communication with one another. The glandular portion of the kidney in *Ostrea* is branched and ramified encircling the visceral mass. In Scaphopoda the kidneys are also paired. As regards the existence of renal organs in Solenogastres there exist two opposite and contradictory views. According to some renal organs are unknown, while others hold that the kidney in Solenogastres is

tube-like and bent on themselves opening into the cloaca by a common duct. Like all other organ systems, the excretory system in Gastropods exhibits great diversities. In majority of the forms two kidneys are present, but they are unequal in size. In some Gastropods only the left kidney (originally the right kidney) is persistent in the adult. *Paludina* possesses two kidneys in embryonic stage, but in course of development, the kidney of the right side disappears. In Aspidobrachia, excepting Neritidae, the left kidney is smaller and the right kidney is larger. The right kidney, in addition to its renal function, subserves as the passage for the genital products. In *Haliotis* the gonad opens into the right kidney by a large aperture. Both the kidneys open into the mantle cavity, one on each side of the anus. But with regard to their pericardial opening there are some variations. In *Trochus*, *Turbo* and *Haliotis* the left kidney is small and opens into the pericardium, while the right one is without the pericardial opening. In *Fissurella* (Fig. 17.64) the right kidney has a pericardial opening.

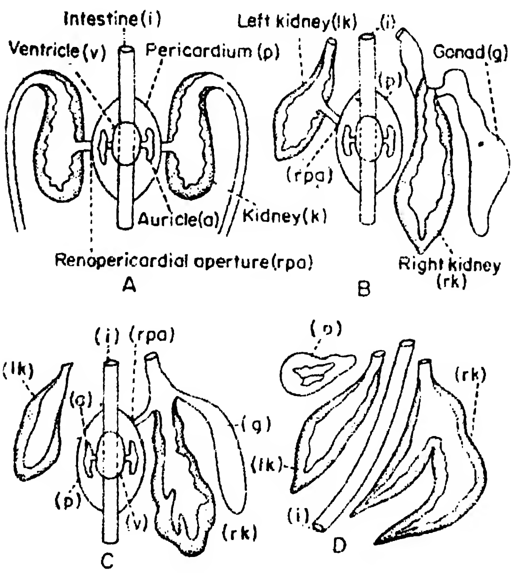


Fig. 17.64. Kidney in a few Gastropods. (A) *Anodonta*. (B) *Haliotis*. (C) *Fissurella*. (D) *Patella*.

In other Gastropods, one of the two kidneys is either greatly reduced or totally absent. The absence of the left kidney appears to be the primitive condition. Generally the kidneys open externally near the anus into the mantle cavity. The kidneys may, sometimes, open into the anus with or without a long ureter. The reno-pericardial aperture varies in different Molluscs. In *Haliotis*, *Trochus* and *Turbo* the right kidney is devoid of reno-pericardial aperture, while the left kidney possesses it. Though not universally accepted, some authors have claimed the absence of reno-pericardial aperture in *Patella*. In some Nudibranchs, like that of *Chiton*, the non-glandular renal sac gives off glandular tubular branches which perform excretory function.

In dibranchiate Cephalopods there are two kidneys which may be separate as seen in *Octopoda* or may be connected anteriorly. Typical condition in Cephalopods is already discussed in the biology of *Sepia*.

In *Nautilus* there are four kidneys and the four afferent branchial vessels are covered by glandular tissue, which project into the pericardium and thus constitute the pericardial gland.

The nitrogenous wastes are eliminated in the form of *guanin* in Cephalopods, as *uric acid* in Opisthobranchs and as *urea* in Lamellibranchs.

RELATIONSHIP OF KIDNEY WITH THE GENITAL ORGANS

In Molluscs, the excretory system and the genital system are closely related. In majority of the Gastropods the renal organ, in addition to its own function, may subserve as the passage for the genital products. In *Chaetoderma* and *Neomenia*, gametes are discharged into the pericardium and they ultimately pass out through kidney. In *Haliotis*, *Fissurella*, *Nerita*, *Patella*, the right kidney acts as an outlet of the genital products. In some Bivalves such as *Avicula*, *Modiola*, *Pecten*, the genital gland communicates directly to the kidney. In *Ostrea cyclas*, the genital gland joins the renal duct. But in most Bivalves the genital and the renal glands are closely placed but they open separately.

REPRODUCTIVE SYSTEM

In Molluscs, the sexes may be united or separate. The Solenogastres, excepting the *Chaetoderma*, are all hermaphroditic. The generative organs are usually paired. In *Chaetoderma* the gonads are fused together to form an unpaired one. There is no separate gonoduct and the sexual products are discharged into the pericardial cavity.

From there these are transported to the exterior by a pair of coelomoducts. The sexes are separate in Polyplacophora. Gonads are unpaired, sac-like structures and are similar in appearance. The gonoducts are paired. Sexes are separate in Scaphopoda. An elongated unpaired gonad is present anteriorly which narrows to form the gonoduct. The gonoduct opens near the anus.

In Bivalves, excepting some forms like *Ostrea, Cardium, Pisidium, Poromya*, the sexes are separate. The genital glands usually lie in the visceral mass and may extend into the mantle lobes as in *Mytilus*. The ovary and testis look alike and are distinguishable by colour only. In hermaphrodite forms, the whole of the generative gland is hermaphrodite. In *Ostrea edulis* and *Plicata* the hermaphroditic gland produces ova and spermatozoa alternately. The male and female follicles in the hermaphroditic gland may be separate as seen in *Pecten* and *Cyclas*. They usually open by a common duct. In fresh-water mussels, *Unio* and *Anodonta*, hermaphroditism is sometimes observed. Some Oysters are protandrous, i.e. the gonad produces first spermatozoa and then ova. In some of these forms a part of the gonad acts as an ovary and the rest as testis. Accessory glands are totally lacking. Most of the Gastropods are dioecious. In dioecious Streptoneura the generative organ is a racemose glandular structure which usually opens into the kidney. But in Neritidae and Pectinibranchs, the gonad has its own independent duct. Accessory glands are usually absent in dioecious forms. In hermaphroditic Streptoneura, single hermaphroditic gland (ovotestis) is present. Accessory glands are quite well-formed in hermaphroditic Streptoneura. Euthyneura is also hermaphrodite and the hermaphroditic organ is more complex in nature. The male and female germinal follicles are usually separate. In Pleurobranchs and majority of the Nudibranchs, several female follicles are arranged around a central male follicle and open into it. The hermaphroditic gland leads into hermaphroditic duct which exhibits wide variations amongst the Gastropods. The hermaphroditic duct is of three types. They are:

Monoaulic forms. In most of the cases as in Bullids and Aplysids, the hermaphroditic duct is undivided.

Diaulic forms. In *Valvata* and majority of the Pulmonata, the hermaphroditic duct is divided into a male part (vas deferens) and into a female part (oviduct). The male and female genital apertures may be quite widely separated as in *Valvata*, many Basommatophora, *Onchidium*, but may be placed very closely as in most Nudibranchs. In Stylommatophora and Siphonophora the two ducts unite to form a common duct which opens into cloaca.

Triaulic forms. In hermaphrodite forms seminal receptacle is present. In monoaulic forms the seminal receptacle opens into the hermaphroditic duct, into the oviduct in the diaulic forms but in *Doris* the seminal receptacle not only opens into the oviduct but also communicates with vagina. Such disposition is usually designated as the *triaulic* arrangement.

Cephalopods are unisexual and in most cases sexual dimorphism is present. Generative gland is single and the gonoduct in one side is usually reduced or vestigial. In *Nautilus*, both male and female, the left gonoduct is vestigial and the right one persists and subserves the genital function. In dibranchiate Cephalopods the left gonoduct is present only in males. The same condition prevails in females excepting Oegopsida and Octopoda (except *Cirrotenthis*) where both the ducts are present and functional.

DEVELOPMENT

The development of Molluscs excepting the Cephalopods is usually indirect. In most of the forms, a typical larval form called **Trochophore** is present. The structure of the Trochophore larva resembles that of annelids. This larval form was first discovered in 1840 by a Swedish Naturalist, Loven. For this reason it was called *Loven's larva* for many years since its discovery. Ray Lankester (1877) named the Loven's larva as *Trochophera*. But in 1878, this larval form was thoroughly studied by Hatschek and he named it *Trochophore*.

The body of the Trochophore larva is more or less oval in shape (see Fig.15.12). The apical pole has a tuft of long cilia at the centre of the lobe and a circlet of cilia called *prototroch*. Another circlet of cilia is present at the meridian of the body. At the basal part of the body two

lobes are present which become transformed into the foot. Close to this, another ciliated band called *telotroch* is present. The region dorsal to the prototroch

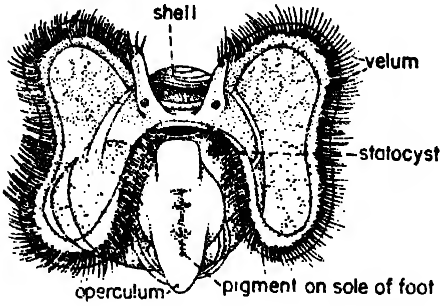


Fig. 17.65. Structure of a veliger larva of *Nassarius reticulatus* (after Parker and Haswell).

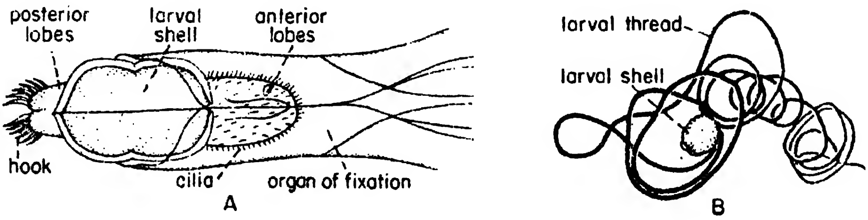


Fig. 17.66. Larvae of fresh-water mussel. A=Lasidium larva of *Anodontites*. B=Haustoria larva of *Mutela* (after Parker and Haswell).

becomes the shell which later on assumes a cup-like form. This stage is called the **Veliger larva.**

The prototroch of the Trochophore expands in the veliger larva to form a ciliated disc called *velum* (Fig. 17.65). In some Gastropods the velum is produced into ciliated lobes.

In Solenogastres development is not fully known. The trochophore larva is present and is provided with calcareous plates. In Polyplacophora typical trochophore larva is present. The apical plate is absent in early phase. Primitive kidneys are lacking. In Scaphopoda also the apical plate and the primitive kidneys are absent. Typical trochophore larva is present in Bivalves and Gastropods. In land pulmonata the youngs assume the adult form and a slight trace of formation of velum is encountered. In other Gastropods typical molluscan larval stages are observed and the larvae may possess certain special organs such as the contractile sinuses (blister-like extensions of the integument assisting larval circulation) and the larval kidneys. In Cephalopods the eggs are large and heavily yolked. There is no larval stage and the youngs are hatched in the form of adult. The two types of larval forms, viz. trochophore larva and veliger larva are seen in different molluscs. They are built more or less on the same structural plan with certain variations and modifications. In fresh-water bivalves, trochophore stage is suppressed and the veliger stage is represented by either *Glochidium larva* or *Lasidium larva* or *Haustoria larva.* The structure of Glochidium larva has already been described in the biology of *Unio* (see Fig. 17.15B). Fig. 17.66 shows the structure of a Lasidium larva in South American fresh-water mussels and Haustoria larva in an African mussel, *Mutela.*

PHYLOGENETIC RELATIONSHIP OF MOLLUSCA

Tunicates, Brachiopods, Bryozoans and Annelids were long regarded to be closely related to Molluscs. Excepting Annelids, relationship with other groups cannot be taken with confidence. The structural and functional similarities with the Tunicates specially in the respiratory and feeding mechanism may be regarded as an instance of physiological convergence without having any phylogenetic significance. The affinities with the Brachiopods and Bryozoans do not warrant any attention, as their structural organisations differ widely. Indications of relationship between Molluscs and Annelids are quite evident from the similarity in the developmental history of the two groups. Existence of Trochophore larva in the two groups is quite significant. The discovery of *Neopilina galatheae* has added more support to the annelidan relationship of Molluscs. *Neopilina* forms a sort of connecting link between Molluscs and Annelids. Based on the typical molluscan plan, *Neopilina*

exhibits segmental arrangement of structures, like shell muscles, auricles, nephridia, gills and gonads. This occurrence cannot be regarded as a chance of coincidence, but must be due to a phylogenetic relationship. Further research on this line is necessary to establish a definite phylogenetic connection between Annelids and Molluscs.

As regards the inter-relationship of the different groups of Molluscs it can be said that the Solenogastres and the Protobranchiate Bivalves occupy the simplest rank. But the primitive position is occupied by the class Monoplacophora which is represented by *Neopilina galatheae*. The Solenogastres, the Polyplacophora and the Gastropods may have evolved from a common ancestor as all of them possess paired ctenidia, paired kidneys and paired auricles. The relationship between the Bivalves and the Gastropods leads to confusion. Presence of bivalve shell in Bivalvia and the asymmetrical anatomical configuration in Gastropoda cannot be interpreted. The Cephalopods possess certain primitive features in their anatomy, but the presence of highly specialised features, such as the transformation of the foot into oral arms and funnel, well-formed nervous system with better-developed eyes, development of cranial cartilage make the Cephalopods completely isolated from the other groups. The Cephalopods demand the highest rank amongst the Molluscs.

ECONOMIC IMPORTANCE OF MOLLUSCS

Molluscs are of great importance to mankind. They are used as food and the shell is used to construct roads and yields lime for our use. Molluscan shell is used for making ornaments and jewelleries. 'Pearl' buttons prepared from shells of bivalves are extensively used.

Formation of Pearl. Pearls have great economic value. Pearls are formed in some particular type of bivalves. Pearl is secreted by the mantle as a protection against foreign objects, usually the parasites. The parasites are recorded to be the larval forms of fluke. The parasite occupies a position between the shell and the mantle (Fig. 17.67A). The larva is enclosed by mantle and forms a sac (Fig. 17.67B) which is formed by the growth of the mantle epithelium. Around the parasite thin concentric layers of *nacre* are formed (Fig. 17.67C). The parasite becomes surrounded by a good size pearl which prevents the parasite from doing any harm. The pearl oysters of Eastern Asia are known as *Margaritifera*. In Japan, pearls are artificially produced by introducing small foreign particle in the mantle in a particular type of Bivalve (*Melagrina*).

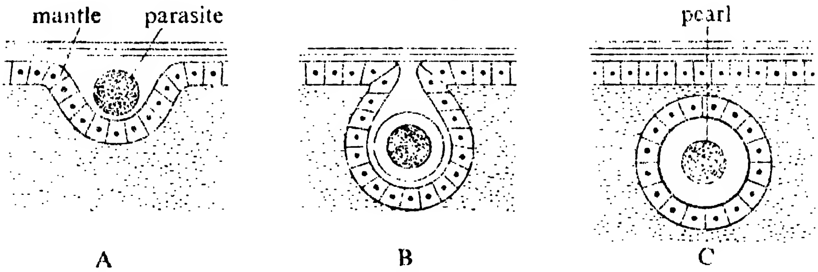


Fig. 17.67. Stages (A–C) of pearl formation.

For centuries, the ink of Sepia has been used as the pigment for the artists and photographers.

Most of the Molluscs are beneficial to mankind but certain forms are indirectly detrimental. The slugs cause great damage to cultivation. *Teredo* damages the wooden portion of the ship immersed in water by boring through it.

SUMMARY

1. Molluscs constitute a very well-defined group of animals. They vary greatly in size and form.

2. They have cosmopolitan distribution and inhabit almost all the environments excepting aerial.

3. Molluscs are notable for their structural

diversities which have resulted out of living in different ecological conditions.

4. Despite their structural diversities they are characterised by having soft unsegmented body protected by calcareous shell developing from the mantle layer.

5. The shell shows extreme variation in shape. Each species has a characteristic shell of its own. The shell may be made up of a single piece, two pieces and even it may be up to eight pieces. Absence of shell in a few is either the case of primitiveness or a case of secondary degeneration.

6. The soft part of the body is covered by a covering called the mantle.

7. The foot is the locomotor organ in molluscs. It may be modified in different molluscs. Such modifications are the consequence of different functional activities, viz. creeping, leaping, burrowing, swimming or reproduction.

8. The true coelom is greatly reduced and is restricted only in the pericardial, renal and genital cavities. The body cavity is a haemocoel.

9. Besides skin, the respiratory organ in aquatic molluscs are mostly the gills. In few cases these true gills are replaced by adaptive gills. The terrestrial forms respire by pulmonary sac or 'lung'.

10. The number of gills in molluscs directly corresponds to the number of auricles.

11. The excretory system comprises of one or two kidneys and pericardial gland. Each kidney has two openings, one internally communicating to the pericardium (*reno-pericardial aperture*) and the other to the exterior called the *nephridiopore*.

12. The blood is colourless and circulates mainly through lacunar spaces, excepting few forms where distinct vessels are present.

13. The nervous system exhibits gradual evolution of complexities from a simpler organisation.

14. In molluscs the sexes are mostly separate and few forms are hermaphrodites.

15. The development is mostly indirect and passes through a common trochophore larval stage. This larval stage in the life of molluscs signifies their phylogenetic relationship with annelids.

16. Molluscs are classified into six classes—Monoplacophora, Amphineura, Scaphopoda, Bivalvia, Gastropoda and Cephalopoda. *Neopilina, Chaetoderma, Chiton, Dentalium, Unio, Pila, Sepia, Octopus*, are some of the common examples of the phylum.

CHAPTER 18

Phylum Echinodermata

The phylum Echinodermata includes a great variety of exclusively marine animals. They are specially noted for their pentamerous and radially symmetrical body constructions (Fig. 18.1). The unique feature of the phylum is the presence of bilateral symmetry in the larval phase. The radial organisation in an adult is regarded as a secondary acquisition and has been derived from the bilaterally symmetrical ancestors.

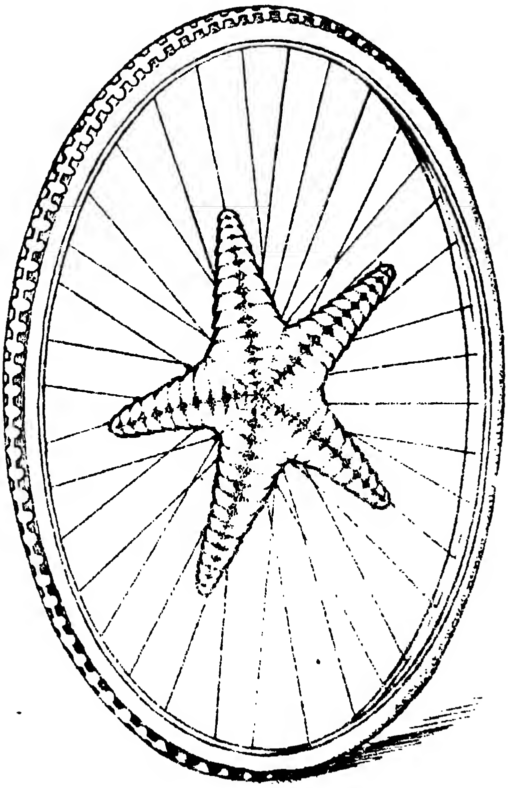


Fig. 18.1. Echinoderm has radially symmetrical and pentamerous body plan.

IMPORTANT FEATURES

The phylum Echinodermata contains a large number of diverse forms. They possess the following important characteristic features: (1) The echinoderms are exclusively marine. (2) The body exhibits radial and pentamerous symmetry in adult, but the larvae are bilaterally symmetrical. (3) Distinct anterior end or head is lacking. (4) The surface of the body is covered by warts or calcareous ossicles and spines. (5) The body is distinguishable into oral and aboral surfaces. (6) The surface of the body is marked by five equidistant radiating *ambulacra* with intervening *interambulacra*. (7) True coelom is present, which develops from the archenteron (enterocoelic). The coelom is lined by *peritoneum* of mesodermal origin. The peritoneum is differentiated into *visceral peritoneum*, covering the outer side of the alimentary canal and the *parietal peritoneum*, lining the inner surface of the body wall. (8) The digestive canal is mostly a coiled tube and the anus is placed dorsally. (9) A characteristic *water vascular system* is present which performs many functions. (10) In most cases, the locomotor organs are the tubular contractile *tube-feet* or *podia*. (11) The *haemal system* or blood lacunar system is present in all echinoderms. It becomes highly developed in Echinoids and Holothuroids. (12)

The nervous system is primitive and consists of radially arranged anastomosing nerve cords. (13) There are no definite respiratory and excretory systems in most of the cases. (14) Reproduction is exclusively sexual except a very few forms which is discussed under the general note on asexual reproduction of this phylum. In most of the echinoderms, the sexes are separate. The gonads are very simple in nature. Fertilization is external. (15) The development of echinoderms involves a large number of bilaterally symmetrical, ciliated and free-swimming larval forms.

CLASSIFICATION IN OUTLINE

The phylum Echinodermata is classified into two Subphyla, Eleutherozoa and Pelmatozoa. The Subphylum Eleutherozoa is subdivided into five classes, *Asteroidea*, *Echinoidea*, *Holothuroidea*, *Ophiuroidea* and *Ophiocistioidea*. The Subphylum Pelmatozoa has five classes, *Heterostelea*, *Cystidea*, *Blastoidea*, *Crinoidea* and *Edrioasteroidea*.

EXAMPLE OF THE PHYLUM ECHINODERMATA —*ASTERIAS*

The genus, *Asterias* is the common representative of the class Asteroidea. The members of this class are generally called the 'Starfishes' or 'Sea-stars'. This name comes from the star-like appearance (Gr. *Aster*=star). There are many species under the genus *Asterias* and the description given below will give a general idea about the anatomical organisation of the group.

Habit and Habitat

Asterias is a marine and widely distributed member of echinoderm. All the species under this genus are benthonic animals, because they inhabit the bottom of the sea. They are quite abundant on various types of sea-bottoms, specially at places where bivalves are available as food. They are carnivorous and predacious animals. They prefer to stay on rocky or stony places where they can hide very easily and lead a sluggish life. Majority of the forms are photonegative and prefer to live in shaded areas. A few exceptions are the *Asterias rubens*, *Asterias gibbosa*, *Asterias panceri*, where positive response to light is observed.

External structures

Asterias has a five-pointed star-shaped body (Fig. 18.2A). The body consists of a *central disc* and five symmetrically placed *arms* (or rays). Sometimes individuals with more than five arms are found in nature. Many starfishes have even four arms. *Leptasterias* has a six-rayed body. The genus *Solaster* has seven to fourteen-rayed body and *Pycnopodia helianthoides* possesses fifteen to twenty-four arms. Occurrence of less than five arms may be possibly, due to mechanical injury. The arms are conspicuously broad at their bases and they gradually taper towards the tips. The body has two surfaces, the upper convex and much darker side is called *aboral* or *abactinal* side. The

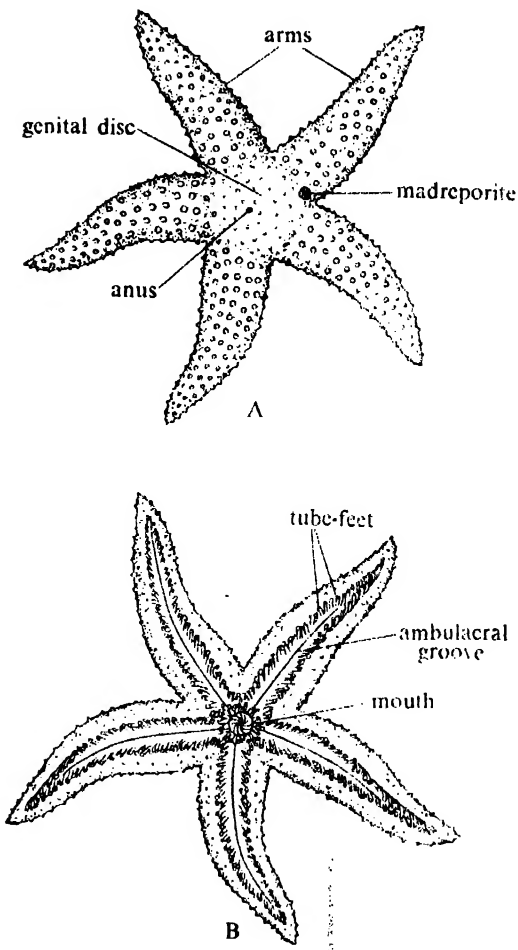


Fig. 18.2. External features of *Asterias*. A. Aboral view. B. Oral view.

other side is flat, less pigmented and is designated as *oral* or *actinal* side. The body exhibits radial symmetry. The imaginary lines dividing the central disc and the arms are called the *radii* and the intervening regions between the radii are

called *inter-radii*. The body is covered by a hard and tough covering containing numerous calcareous *ossicles*. At the centre of the oral surface of the central disc, a five-rayed aperture called *mouth* or *actinosome* (Fig. 18.2B) is present. This opening is surrounded by a membranous *peristome* and it also possesses five groups of *oral papillae*. Five narrow *ambulacral grooves*, one on each arm, run orally from the five-rayed aperture to the extremity of the arms. The edges of these grooves are provided with two or three rows of movable calcareous *ambulacral spines*. Besides the ambulacral spines, rows of immovable stout spines are also present. The aboral side contains numerous irregular rows of short and stout spines supported by ossicles. The oral and aboral surfaces of the body are separated by a row of prominent spines. Many *dermal pores* are situated in the spaces between the ossicles on the aboral side.

A minute aperture, called *anus*, is situated at the centre of the aboral surface. On the same side of the body, between the bases of two of the five arms (*bivium*), there lies a structure called *madreporite* (Fig. 18.2A). The madreporite is a flat disc-like body with radiating grooves. The presence of more than one madreporite in some species is possibly due to increase of the number of arms beyond the normal number of five.

Scattered all over the body surface there are many microscopic bodies called *pedicellariae* (Fig. 18.3A), each consists of a flexible *stalk* and three calcareous pieces —one *basilar* and two *jaws* or *valves*. The jaws are attached with the basilar piece. The pedicellariae are modified spines. This particular variety of pedicellariae is called the pedunculate type. Two types of pedunculate pedicellariae are encountered in Asterias (Fig. 18.3B). These are: (1) *Straight Pedicellariae*—when the two jaws remain more or less straight on the basilar piece. (2) *Crossed Pedicellariae*—when the basal portions of the jaws are curved and cross each other.

The pedicellariae are protective organs. The jaws are movable on the basilar piece. The jaws are operated by two sets of muscles—two pairs of *abductor muscles* and

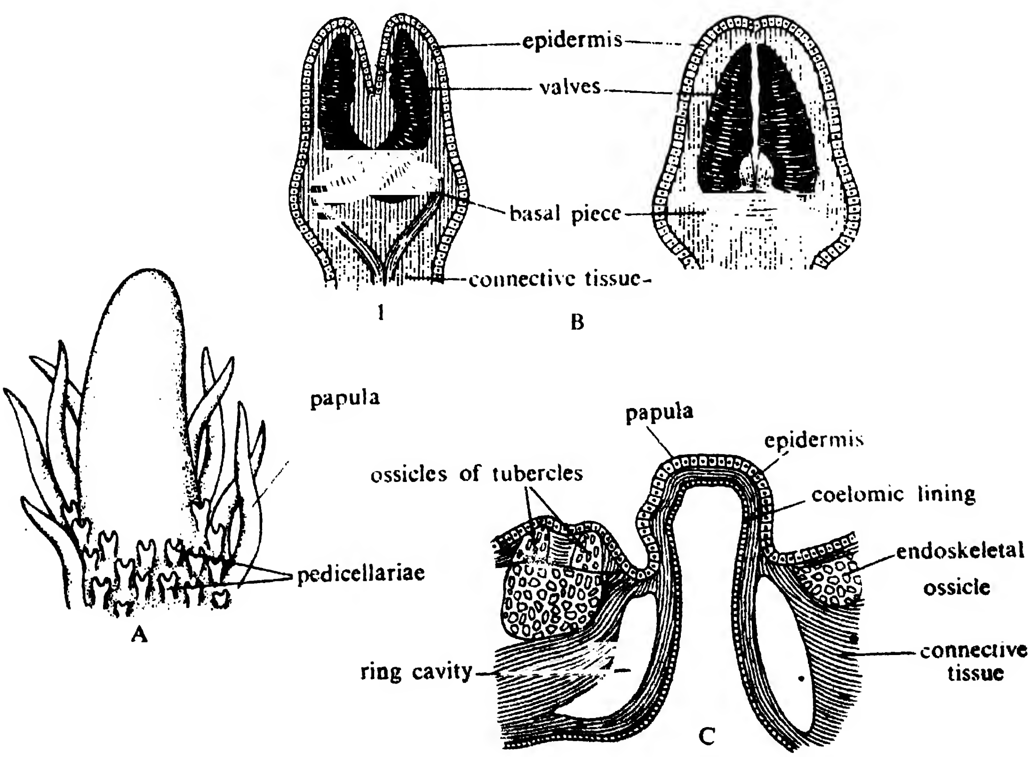


Fig. 18.3. A. Enlarged view of the spine with papulae and pedicellariae of *Asterias*. B. Structure of Pedicellariae. (1) Straight type, (2) Crossed type of *Asterias*. C. Diagrammatic sectional view of papular region of *Asterias*.

one pair of *abductor muscles*. In natural condition and in well-preserved state two double rows of *tube-feet* or *podia* are seen in the ambulacral grooves. Each tube-foot or podium has a soft tubular body and it ends in a sucker. These are locomotor organs and are capable of great extension. At the tip of the ambulacral groove, sense organs are placed. A minute red spot, called the *eye*, is present at the extremity of each ambulacral groove on the oral side. The eye is composed of several ocelli. Just above the eye lies a median unpaired *terminal tentacle*. This tentacle resembles a tube-foot but lacks the sucker and is regarded as olfactory organ.

Structure of body wall

The body is covered externally by *cuticle*. The cuticle is differentiated into an outer thick homogeneous layer and a very delicate inner layer. The *epidermis* is situated beneath the cuticle. The shape and structure of the cells composing of the epidermis vary greatly at different regions of the body. Usually these cells are of ciliated columnar types. Besides them, several other cells are also present. The cells are *neurosensory* cells, *pigment* cells and *glandular* cells. The gland cells are of two varieties—*goblet* or *mucous* cells and *muriform* gland cells. The muriform types contain coarse granules and the goblet types have very fine granules. Beneath the epidermis lies a network of nerve fibrils. The *dermis* is comparatively thicker. It is mesodermal in origin and is composed of fibrillar connective tissue. The epidermis and the dermis are separated by a delicate *basement membrane*. The dermis contains the endoskeletal ossicles and also possesses a system of canalicular haemal spaces. Beneath the dermis lies the *muscular* layer. This layer is divided into an outer circular muscle layer and an inner longitudinal muscle layer. The innermost layer of the body wall is lined by the *coelomic epithelium*.

Skeleton

The rigidity of the body of Asterias is due to the presence of definite skeleton. This supporting skeleton comprises of the main deeper skeletal elements embedded in the dermis and the superficial skeleton in the forms of spines, warts and tubercles which are borne on the deeper skeleton. The ossicles are of various shapes and bound together by connective tissue.

The ossicles have distinct pattern of arrangement. The mouth is surrounded by five plate-like *oral ossicles*. Each ambulacral groove is supported by double rows of rod-like *ambulacral ossicles*. These ossicles are articulated with the *adambulacral ossicles* at their aboral ends like an inverted 'Λ'. The apex of the 'Λ' projects into the coelom and forms a prominent *ambulacral ridge*. The ambulacral ossicles are movably articulated so as to allow the closure and opening of the ambulacral groove. A row of lateral *adambulacral ossicles* meets the ambulacral ossicles on their outer ends. The adambulacral ossicles bear movable spines. In some forms of Asterias, one or two rows of additional ossicles are present. They are called *supramarginal* and *inframarginal ossicles* depending on their position. The marginal ossicles form the dorso-lateral sides of the arms and usually remain covered by small ossicles. A series of *carinal ossicles* forms the mid-dorsal skeleton of the arms. Between the carinals and the marginal ossicles there may be a number of elongated dorso-lateral ossicles.

The arrangement of skeletal elements on the aboral side is indistinct in adult, but in a freshly metamorphosed Asterias the arrangement is distinct. At the middle of this side a *central plate* is present which bears the anus. This central plate is surrounded by five *interradial plates*. One of such plates incorporates the madreporite. The interradial plates are surrounded by radially placed *terminal plates*. In starfishes where the number of arms exceed five, the interradial and terminal plates increase with the number of arms. As the arms grow in length the terminal plates are also shifted to the tip and additional row of plates develops behind the terminals. These plates which develop behind the terminals constitute the carinals of the mid-dorsal line of the arms.

Section of arm

If one of the arms of Asterias is sectioned the following structures become visible (Figs. 18.4 and 18.5):

1. The wall of the arm shows the appearance of an arch with its convexity upwards. The aboral side is thicker than the oral side.

2. The body wall consists of epidermis, dermis, muscular layers and coelomic epithelium. The epidermis consists of ciliated

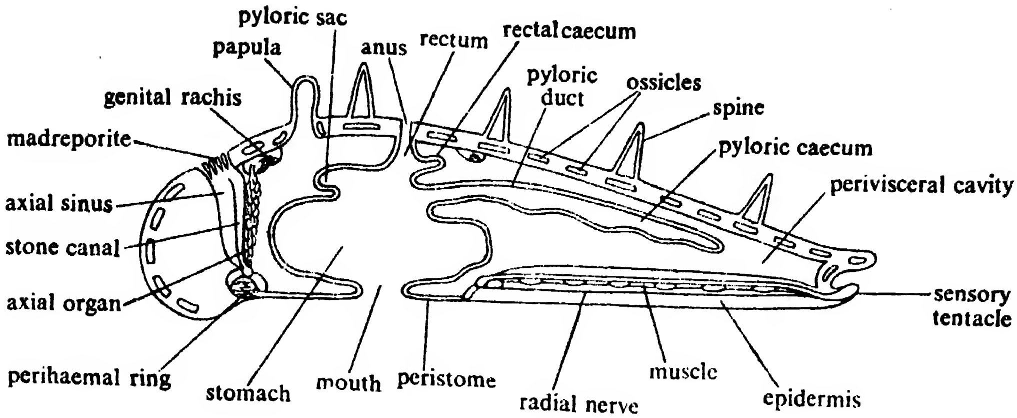


Fig. 18.4. Diagrammatic longitudinal section of the disc and an arm of *Asterias*.

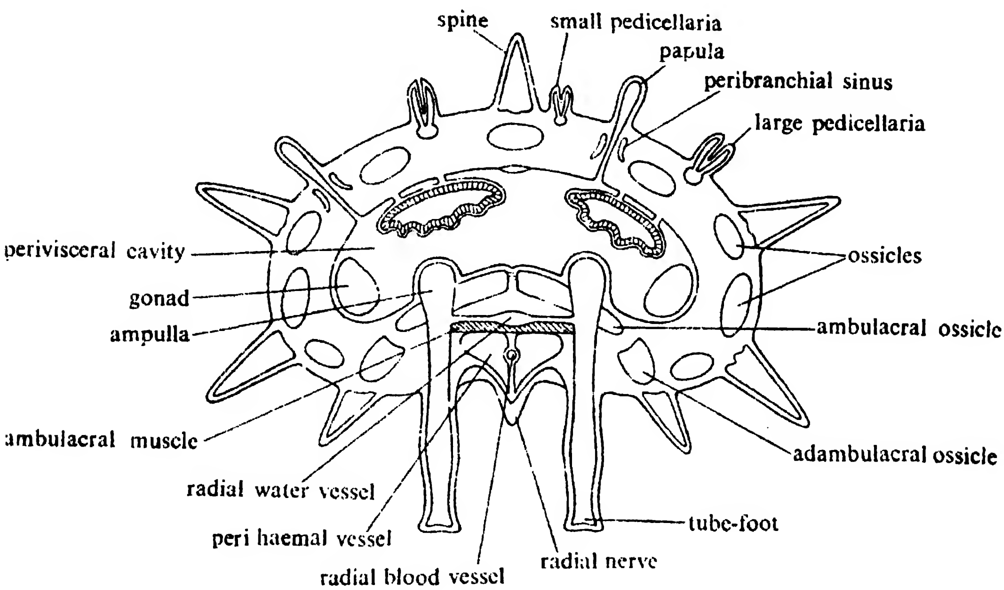


Fig. 18.5. Diagrammatic transverse section of an arm of *Asterias*.

columnar cells, neurosensory cells, pigment cells and two types of gland cells. Above the epidermis there is the cuticle. Beneath the epidermis lies the basement membrane. The dermis is mesodermal in origin and is fibrillar in nature. The dermis is thicker than epidermis and contains haemal spaces and endoskeleton in the form of ossicles. The muscular layer is situated beneath the dermis. The muscular layer is differentiated into an outer circular layer and an inner longitudinal layer. The coelomic epithelium forms the inner lining of the body wall.

3. The surface of the body bears spines, tubercles, pedicellariae and warts which are borne on the deeper skeletal elements.

4. The deeper skeleton consists of ossicles of various shapes. The ambulacral groove is supported by two rod-like ambulacral ossicles, articulated at their aboral ends like an inverted 'Λ' with the upper transverse ambulacral muscle. Two adambulacral ossicles, one on the lateral side of each ambulacral ossicle, are present. The adambulacral ossicles bear movable spines. The upper dorso-median side of the arm contains carinal ossicle. Between the carinal and adambulacral ossicles there exist supra- and infra-marginal ossicles which form the lateral walls of the arm.

5. Projecting between the dermal ossicles there are many hollow outgrowths of

the body called respiratory papulae. They are quite abundant on the aboral surface.

6. The spacious cavity enclosed by the body wall is called coelom. Scattered coelomocytes are present in the coelomic space.

7. In the ambulacral groove there are double rows of tube-feet. The tube-foot has a tubular body ending in a sucker. Each tube-foot is continuous with a bladder-like ampulla situated in the cavity of the arm.

8. In the cavity of the arm, there are two pyloric caeca which remain suspended from the aboral body wall by two mesenteries.

9. Two gonads are located in the cavity of the arm between the pyloric caeca and the ampullae.

10. Towards the oral side, sectional views of radial canal and lateral or podial canals of the water vascular system are seen.

11. Towards the oral side, sectional view of the radial nerve, Lange's nerve, hyponeural sinus with its dividing septum containing radial haemal strand are present.

Coelom

Asterias has a spacious coelom. The coelom is enterocoelic in origin. It surrounds the alimentary canal and the gonads. Besides this main perivisceral coelom, there are many small coelomic cavities like water vascular system, axial sinus, perihaemal cavities and genital sinuses. The inner surface of the perivisceral coelom is lined by ciliated epithelium which is differentiated into two separate layers. The parietal layer covers the inner surface of the body wall and the visceral layer forms an investment for the different organs contained in the body. The coelom is filled up with coelomic fluid. This fluid is chemically similar to sea water in composition and contains amoeboid coelomocytes. However, potassium is present in higher concentration than in sea water (Robertson, 1949). Traces of amino nitrogen are reported to be present in asteroids (Ferguson, 1964). A small amount of reducing sugar is present in perivisceral fluid of *Asterias forbesi* (Ferguson, 1964). Excretory products like urea and ammonia are also present in coelomic fluid (Delaunay, 1931). The coelomocytes are highly phagocytic and are supposed to be excretory in function.

Digestive system

The digestive system (Fig. 18.6A) includes alimentary canal and digestive glands. The alimentary canal is a very short straight tube. It extends from the oral to

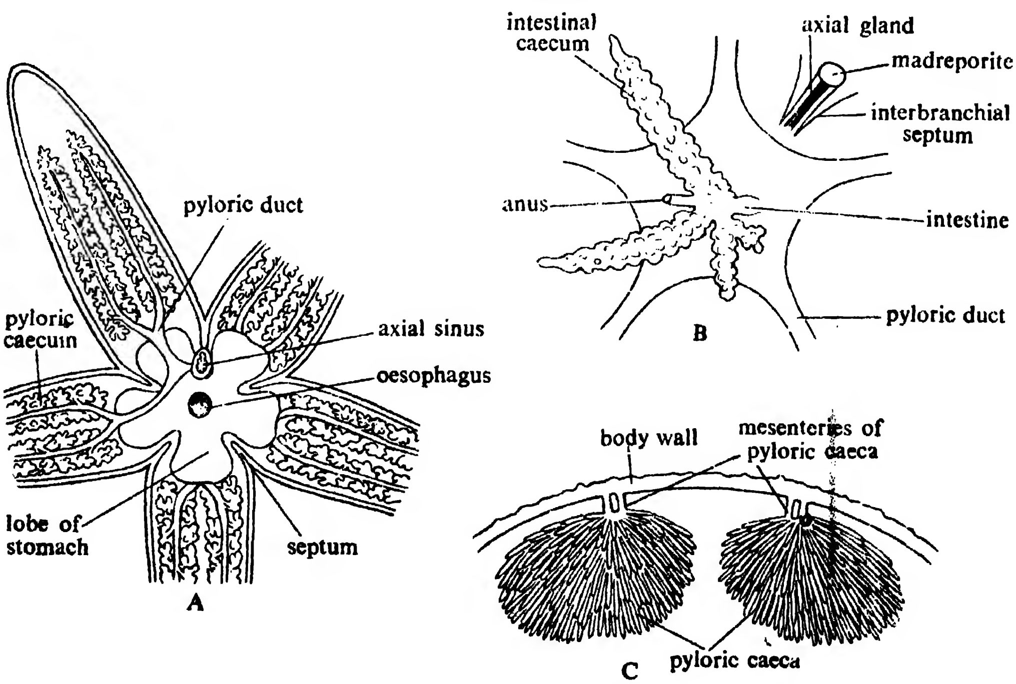


Fig. 18.6. A. Aboral view of the digestive tract of *Asterias*. B. Pyloric stomach and intestinal caeca of *Asterias* (enlarged view). C. Attachment of pyloric caeca with the aboral wall of arm of *Asterias*.

the aboral side of the body. The *mouth* is located near the centre of the oral surface. The mouth leads into a very short and wide *oesophagus*. The oesophagus passes into a spacious *stomach*. The stomach is distinctly divided into two parts by a horizontal constriction. The voluminous anterior portion is called *cardiac stomach* and the smaller posterior chamber is called *pyloric stomach*. The cardiac stomach is a five-lobed sac. Its inner wall becomes greatly folded. The cardiac part is attached to the ambulacral ridge by two *gastric ligaments* and is capable of being everted through mouth. The cardiac stomach communicates with the pyloric stomach. The pyloric stomach is a pentagonal sac and each angle is produced into a pair of large *glandular appendages*. There are, in all, ten such glandular structures. They possess various names such as *pyloric caeca* or *digestive glands* or *brachial caeca* or *hepatic caeca* (Fig. 18.6B). The pyloric caeca are glandular in nature and secrete digestive enzymes. They start as cylindrical duct which immediately divides into two tubular stems. The tubular stems give off two series of short *lateral branches*. The stem extends up to the tip of the arms. The lateral branches dilate at their tips to form numerous small pouches. The pyloric caeca are attached with the aboral wall of the arm by mesenteries (Fig. 18.6C). The pyloric caeca have the typical histological picture of the alimentary canal, but the lining epithelium is very thick. It is lined by four types of cells. The cells are: (1) Flagellated cells—with long flagella to maintain a constant circulation of fluid. (2) Secretory cells—produce digestive enzymes. (3) Mucous cells—secrete mucus. (4) Storage cells—contain lipid, glycogen, polysaccharide-protein complex as stored food. Heyde (1922) performed a series of experiments on digestion in *Asterias* and advanced the idea that proteolylic activity is encountered in both stomach and pyloric caeca. But the other enzymes, like amylase, lipase, etc. are not found.

The pyloric stomach opens into a short conical *intestine* which opens to the exterior through *anal aperture* situated on the aboral side. From the intestine, two hollow *intestinal caeca* are given off interradially. These intestinal caeca are provided with several short irregular branches. The greatly folded inner lining of the intestinal caeca contains mucous and gland cells. These are brownish in colour and secrete brown coloured fluid. The exact physiological role of these structures is not known but, with all probability, they help in excretion. These structures are homologised, by many, with the respiratory trees of the holothurians.

The histological picture of the alimentary canal reveals that the outer layer is composed of the visceral layer of the coelomic epithelium. The next layer is the muscular layer and the innermost layer comprises of endoderm or enteric epithelium.

Respiratory system

Respiration is carried on by numerous *papulae*. The papulae are delicate hollow outgrowths of the body wall (see Fig. 18.3C) and project between dermal ossicles. These are distributed abundantly on the aboral side of the body. The histological structure is same as that of the body wall excepting the thinness of the dermis and the absence of dermal skeleton. The lumen of each papula is continuous with coelom and is lined by ciliated coelomic epithelium. Through these respiratory papulae exchange of oxygen and carbon dioxide takes place by diffusion. In addition to the papulae, the water vascular system also helps in respiration. Meyer (1935) proved that the tube feet of each ambulacral groove in *Asterias rubens* are responsible for approximately 10% of total O_2 uptake.

Water vascular system

The water vascular system is the most characteristic system in Asterias and plays a number of vital functions (Fig. 18.7A). It starts with the *madreporite* and gives off a system of vessels traversing the body. The madreporite is a round calcareous plate (Fig. 18.7B) and has an interradial disposition on the aboral surface. The madreporite contains furrows which have numerous pores at the bottom. Each pore leads into a *pore canal*. The number of pores and pore canals may be about two hundred. The pore canals unite to form collecting canals which open into madreporic ampulla. This ampulla proceeds downwards as an 'S'-shaped cylindrical *madreporic* or *stone canal*. The wall of this canal is supported by a number of calcareous rings,

hence the name stone canal. From the wall of the stone canal projects a ridge which bifurcates into two lamellae. The lamellae become spirally rolled to occupy a considerable portion of the lumen of the stone canal. In some species of starfishes, the lumen of the stone canal becomes very much complicated due to extensive development of the lamellae. Most of the pore canals from the madreporite open to the stone canal and the rest open to the axial sinus.

The stone canal opens below into a considerably wide pentagonal *ring canal.* In certain starfishes, there occur pear-shaped sacs called *polian vesicles* which are connected with the ring canal interradially. The usual number of polian vesicles are ten, two in each interradius. But the number vary in different starfishes. In Asterias, polian vesicles are wanting as such. The neck of each polian vesicle is provided with a pair of small spherical glandular structures called *Tiedemann's bodies.* As the Polian vesicles are absent in Asterias, the ring canal gives off interradially nine such Tiedemann's bodies. The interradius which bears stone canal has only one Tiedemann's body. The significance of these bodies is not properly known. They are regarded by many workers as lymphatic glands manufacturing amoebocytes of the water vascular fluid. Besides, Kowalevsky (1889) first observed that if a sea-star is allowed to live in sea-water containing Indian ink or some vital dye, the colour is accumulated in the epithelial cells lining their lumina. But the absorptive function of the epithelial cells is not yet confirmed.

The stone canal lies folded in the wall of a wide axial sinus, a part of the haemal

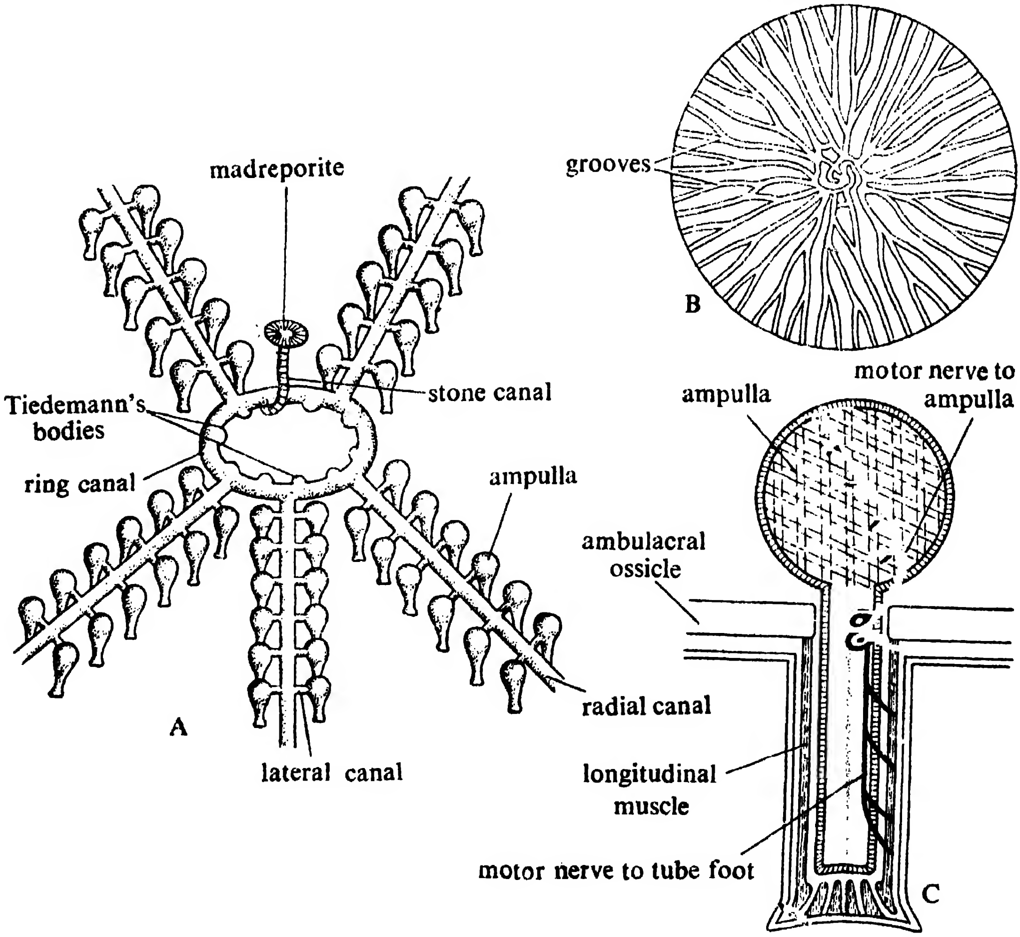


Fig. 18.7. A. Water vascular system in *Asterias*. Note that in *Asterias* the polian vesicles are absent. B. Enlarged view of the madreporite of *Asterias*. C. Diagrammatic sectional view of a tube-foot and its nerve supply in *Asterias*.

system. The axial sinus communicates with the stone canal aborally and opens to the exterior through some pores of the madreporite. Associated with the stone canal and infolded in the wall of the axial sinus there lies the axial organ (see Fig. 18.8B). The actual function of this organ and its relation with the water vascular system is still unknown.

The ring canal gives off five *radial canals* along the ambulacral grooves of the arms. The radial canals run up to the tip of the arms and end as the lumen of the terminal tentacle. The radial canal gives out small side branches called the *lateral* or *podial* *canals*. Each lateral canal, after reaching the ambulacral pore, divide at right angles into two branches. One of the branches, is continued as the lumen of the *tube-foot* (Fig. 18.7C) and the other as the cavity of the *ampulla*. The ampullae are rounded sac-like bodies arranged in one or two rows on each side of the ambulacral ridge. Usually one ampulla is present in each tube-foot. In certain starfishes, the ampulla may be bilobed (*Astropecten irregularis*), with a constriction at the middle. In Asterias, the ampullae are simple and undivided.

The vessels of the water vascular system have muscular wall with an internal epithelial lining. The muscular layer becomes highly developed in the tube-feet and ampullae.

Haemal system or Blood lacunar system

The blood lacunar system as such is absent in Asterias, but its function has been taken up by a special system called haemal system. This system of channels is enclosed by coelomic spaces (Fig. 18.8A). These spaces are sometimes designated as perihaemal system. The haemal channels are lined by coelomic epithelium with an inner connective tissue layer (Fig. 18.8B). The haemal channels are actually intercommunicating spaces and are not true blood vessels. They develop like the haemocoel of other animals. So the term perihaemal system comprising the cavities enclosing the haemal channels seems rather confusing. In our present discussion only the haemal system has been described.

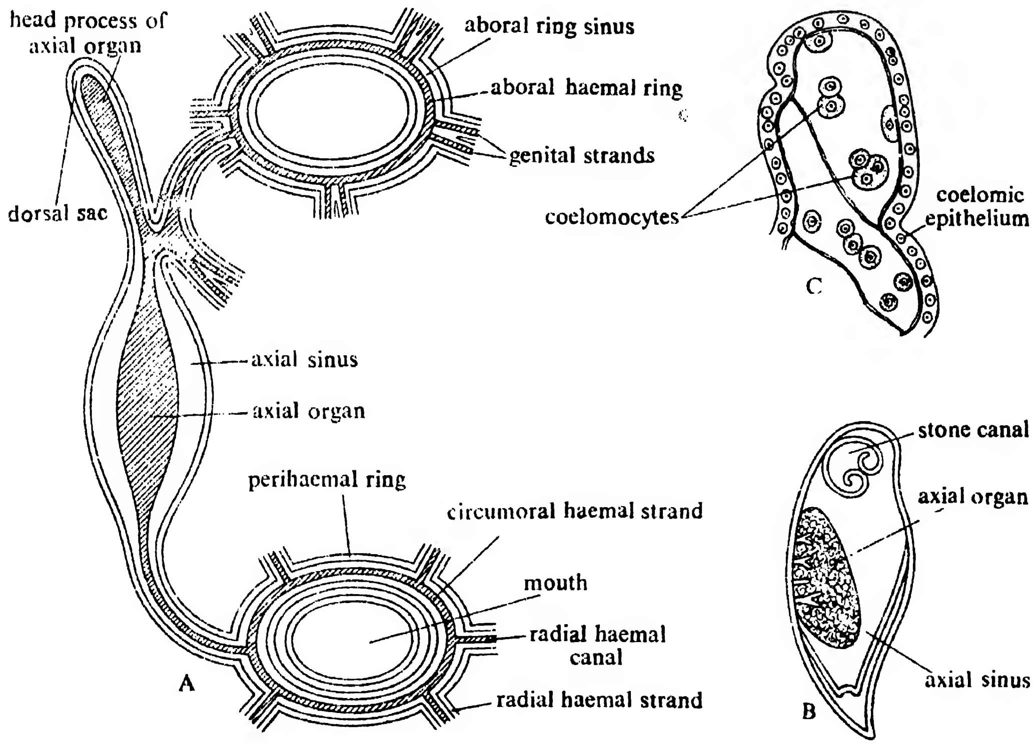


Fig. 18.8. A. Haemal system of *Asterias*. B. Sectional view of haemal complex in *Asterias*. C. Sectional view of a haemal channel in *Asterias*.

The haemal system includes an *oral haemal ring* which proceeds in the septum of the hyponeural sinus. The oral haemal ring gives off *radial haemal sinuses* into the arms. Each arm has one radial haemal sinus which is situated in the septum of the hyponeural radial haemal sinus and gives off branches to the tube-feet. In the aboral side there is an *aboral haemal ring* which gives haemal branches (*genital branches*) to the gonads. The oral haemal ring is communicated with the aboral haemal ring by an ascending *haemal plexus* in the *axial gland*. Two *gastric haemal tufts* open into the haemal plexus of the axial gland towards its opening into the aboral haemal ring. The gastric tufts are the only part of the haemal system which is not enclosed by the so-called perihaemal cavities. According to some authors about twenty *pyloric haemal channels* are in communication with the axial gland and haemal plexus through gastric haemal tufts. Each pyloric caecum is attached with the aboral wall of the arms by a pair of mesenteries and each mesentery contains a pyloric haemal channel at the base. Through these channels digested food is conveyed to the haemal system.

The cavities of the haemal channels are filled with coelomic fluid containing coelomocytes (Fig. 18.8C). This fluid in the haemal system undergoes slight movement and helps in the distribution of digested foods to different parts of the body. The haemal plexus of the axial gland is regarded as the 'heart' of the haemal system. Besides the axial gland, contractility of the terminal process of the axial gland, gastric haemal tufts, aboral haemal ring is also observed by some workers.

Axial complex

Asterias has a very well-formed axial complex comprising a coelomic cavity enclosing the stone canal and axial gland (Fig. 18.8B). The axial complex remains intimately associated with the interbrachial septum. The axial sinus is a thin-walled tubular cavity which opens orally into the inner smaller ring of the hyponeural ring sinus. It opens aborally into the genital sinus and finally into the ampulla of the stone canal. The axial gland is a long spongy body of brown or purple colour and gives a small terminal process at the aboral end. This process is surrounded by a contractile closed sac named as *terminal sac* or *dorsal sac* or *madreporic vesicle*. This vesicle is situated very close to the ampulla of the stone canal, but has no connection with it. The axial gland terminates orally in the septum of the hyponeural ring sinus. The axial gland is variously called as heart, ovoid gland, brown gland, septal organ and dorsal organ. The function of the axial gland and its relation to other systems are still disputed. It has an interior core of connective tissue traversed by many spaces containing coelomocytes and externally it is covered by a coelomic epithelium. The histological picture reveals its similarity with the haemal system and both are closely associated.

Locomotion

The water vascular system in Asterias operates on the principle of hydraulic pressure during movement. This system is indirectly concerned with the locomotion of the animal. The water vascular system is always filled with fluid and the loss of fluid from the tube-feet is instantaneously compensated by the intake of water into the system through the madreporite. In Asterias, locomotion is caused by the action of the tube-feet. These are present as two double rows on each ambulacral groove. They have soft tube-like bodies with sucker at the tips (see Fig. 18.7C). They are capable of being extended outwards and forwards to the direction in which the animal moves. By alternate extension and contraction of all the tube-feet, the starfish progresses quite steadily over the surface.

When the animal moves to a particular direction, the arms on that side are lifted from the surface and the tube-feet become greatly extended. The extension of the tube-feet is caused by the contraction of the ampullae. Due to contraction, the fluid from the ampullae is forced through the tube-feet. The presence of valves at the bases of the lateral vessels prevents re-entry of water into the radial canals. As the tube-feet are extended towards the direction of movement, the suckers at the ends of the tube-feet adhere to the substratum. The suckers produce vacuum cup at the centre. The tube-feet gradually contract and thus the animal is brought forward. The tube-feet finally relax and release their holds on the substratum. The tube-feet

again extend forward to apply the suckers to the new places by the same fashion. By such alternate process of contraction and relaxation of tube-feet the animal moves very slowly. This type of progression is possible when the animals move on hard surface under water. During progression the tube-feet work in this manner by extending towards one direction. This coordinated action of the tube-feet is controlled by the nerve ring and the radial nerves. It is also observed that the tube-feet are lined by long gland cells which secrete sticky fluid to lubricate the process. In Asterias, the tube-feet are provided with suckers. In other mud-dwelling forms the suckers become inactive and they utilise the tube-feet as miniature legs.

Excretory system

Definite excretory organ is lacking in Asterias. By injecting various coloured substances into the coelomic fluid, it is observed that the coelomocytes play the main role in excretion. The intestinal caeca, in addition to other functions, extract waste products from the coelomic fluid and eliminate the wastes through alimentary canal.

These nitrogenous waste products diffuse out from the body into the coelomic fluid. These are immediately engulfed by the wandering coelomocytes and pass out of the body through the papulae. The nitrogenous wastes include ammonia, urea and traces of uric acid. The presence of creatine and creatinine in Asterias is very significant, because these substances are not found in any other invertebrates.

Nervous system

The nervous system of Asterias is very simple. It includes only nerve net and has no central ganglionic formation. The nervous system consists of three systems *oral or ectoneural system*, *deep or hyponeural system* and *coelomic nervous system*.

ORAL OR ECTONEURAL NERVOUS SYSTEM. This system includes the main part of the nervous system and is situated below the epidermis. This includes a *nerve pentagon* situated in the peristomial membrane surrounding the mouth. The nerve pentagon at each radius gives off a *radial nerve* which runs as a slender thick band throughout the ambulacral groove. The radial nerve is situated just below the radial canal as median integumentary thickening. The radial nerve ends as a *sensory pad* or *cushion* at the base of the terminal tentacles. The radial nerve gives branches to the tube-feet and becomes continuous with the subepidermal nerve plexus of the body wall. The nerve pentagon and the radial nerves consist of nerve fibrils with scattered bipolar and multipolar nerve cells. The radial nerve appears like a thick 'V'-shaped body below the hyponeural sinus. It is separated from the hyponeural sinus by a thin dermis and coelomic epithelium.

DEEP OR HYPONEURAL NERVOUS SYSTEM. The different nerves composing this system are motor nerves. This nervous system comprises of *Lange's nerves*. Lange's nerve is a plate of nervous tissue situated beneath the coelomic epithelium of the hyponeural sinus and forms a lateral lining on the wall of this sinus. Lange's nerve extends as five inter-radial nerve thickenings above the main nerve pentagon of the ectoneural system. Each Lange's nerve innervates the muscles of the corresponding arm.

COELOMIC NERVOUS SYSTEM. The subepithelial nerve plexus at the outer ends of the ambulacral ossicles forms *marginal nerve cord* on two sides of the arms. The marginal nerve cord gives off *lateral motor nerves* which proceed to the aboral side between the adambulacral and ambulacral ossicles to reach the coelomic lining. Beneath the entire coelomic lining the nerves form plexus which innervates the body wall musculature and the gonads.

Sense organs

The neurosensory cells, terminal tentacles and the eyes are the sensory units in Asterias.

Neurosensory cells. These cells are tactile in function and act as chemoreceptors. They are present throughout the body, but are quite abundant in the suckers of the tube-feet, in the ambulacral regions, in the epidermis, at the base of pedicellariae and spines. Each neurosensory cell has a slender fusiform body. The proximal end is connected with subepithelial nerve plexus and the distal end goes up to the cuticle.

Terminal tentacles. They are regarded as tactile receptors. These sensory organs help to survey the environment during locomotion.

Eyes. They constitute the major sense organs. At the base of each terminal tentacle towards the oral side a pigmented eye spot is present. Each 'eye' consists of numerous photoreceptors in the forms of cup-like pigmented *ocelli*. Each ocellus is covered over by cuticle. The wall of the cup is composed of red pigmented cells and retinal cells. The epidermis beneath the cuticle of the cup may form lens which may be absent in some cases. The number of ocelli per eye may be about 80–200. The number may even increase with age.

Reproductive system

Reproduction, in Asterias, is mainly sexual but asexual reproduction by splitting of the body also takes place. The sexes are separate but sexual dimorphism is absent. The ovaries and testes are similar in appearance. They are situated in the same place of the body. There are ten testes or ovaries, two in each arm of the body. The proximal ends of the gonads are attached to the aboral body wall near the interbrachial septum. Each gonad is an elongated branched body which becomes considerably enlarged at maturation stage. The gonad is enclosed in a coelomic genital sac. Microscopical examination reveals that the gonad is lined by a germinal epithelium with a connective tissue matrix containing germ cells. Very near to the point of attachment with the interbrachial septum, each gonad gives out a very short ciliated gonoduct which opens to the exterior through gonopore situated on the aboral side at the angle of the arms.

Fertilization

The sex cells are set free into the sea water and the fertilization is thus external.

Development

The developmental sequences are best known in an allied form of Asterias, *Asterina gibbosa* (Fig. 18.9). The eggs are

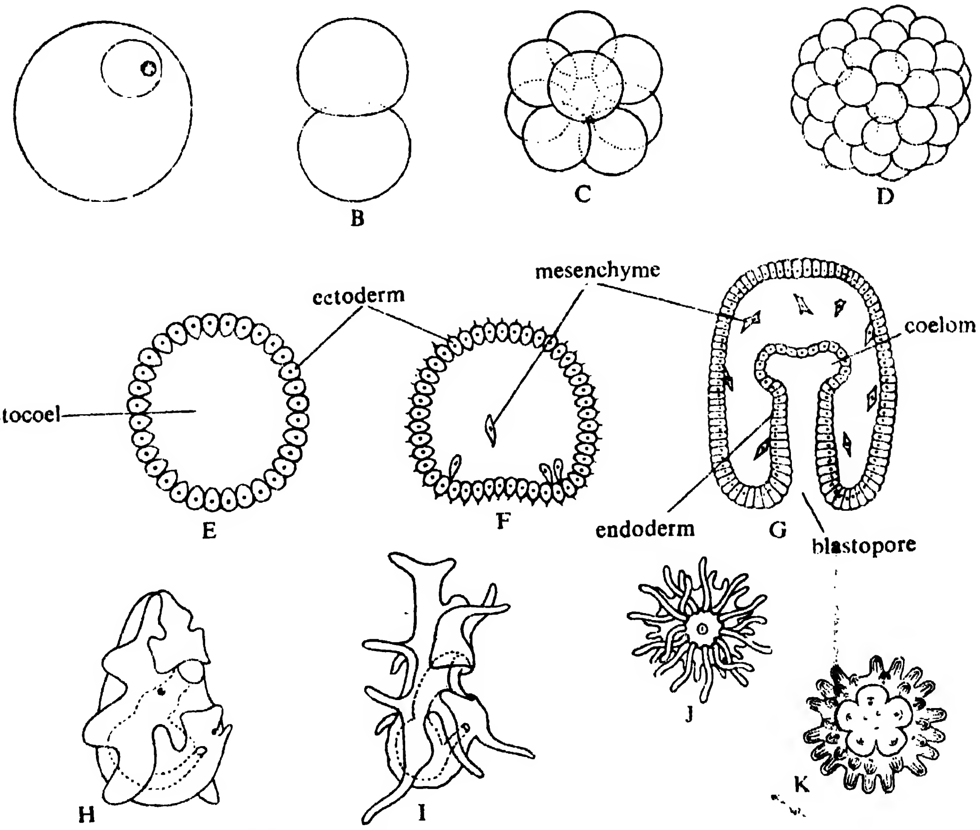


Fig. 18.9. Developmental stages of *Asterias*. A. Egg. B–D. Stages of segmentation. E. Blastula. F. Early gastrula. G. Gastrula. H. Early Bipinnaria larva. I. Brachiolaria larva. J. Aboral side of young *Asterias*. K. Oral side of young *Asterias*. Note that the figures E–G are sectional views.

spherical and yolky. Each egg measures about half of a millimetre in diameter. After fertilization the zygote divides into two. The cleavage is total and is practically equal. The two cells produced by first cleavage, divide to form four cells. The process of such division goes on until thirty-two cells are produced. These cells are arranged in such a manner that they enclose a central cavity (*blastocoel*) and this stage is called *blastula*. The outer surface develops vibratile cilia and the inner cavity increases by repeated cell divisions. Gastrulation starts as a process of invagination and a double-walled gastrula is formed. The invaginated sac forms the *archenteron* and opens to the exterior through the *blastopore*. The gastrula elongates and the cilia over the surface of the body become restricted along definite bands. The gastrula is transformed into a larva in course of time.

The shape of the larva gradually changes. With the elongation of body, the blastopore, at the middle of the two poles, becomes subsequently shifted to the posterior end. The outer layer is converted into ectoderm. The space between the ectoderm and the endoderm becomes occupied by the mesenchyme. The cavity of the gastrula becomes distinguishable into two parts, the *archenteron* and the *enterocoel*. The narrower proximal part is called the archenteron and the wider terminal part is called the enterocoel. The blastopore becomes the larval anus. The enterocoel gives off right and left lateral pouches called the *enterocoelic pouches*. The enterocoel becomes completely closed off from the gut and becomes divided into three parts, an anterior part and two lateral (right and left) parts in the form of pouches. The left pouch grows faster than the right and proceeds posteriorly in the space between the body wall and the alimentary canal. The pouches coalesce posteriorly to give origin to the coelom in adults. The anterior undivided portion becomes subsequently cut off from the lateral pouches and forms the coelom of the preoral lobe. This part gives off a five-lobed extension called *hydrocoel* on the left. From the hydrocoel the entire adult ambulacral system develops. Two apertures appear on the surface—one is the mouth on the ventral side and the other on the dorsal side called the dorsal pore. The mouth opens into the larval stomach and the larval anus soon closes. The particular type of larva in starfishes is called *Bipinnaria larva*. It has bilaterally symmetrical lobes with ciliated bands. The Bipinnaria larva is succeeded by *Brachiolaria* stage. The detailed structures of these larval forms have been discussed separately in the general notes on Echinodermata.

The preoral lobe of the larva assumes an elongated cylindrical *larval organ*. An elevation, the rudiment of sucker, develops at the middle of the larval organ. The sucker helps in the attachment of the larva during metamorphosis. The larva is transformed into the five-rayed starfish by the elimination of the preoral lobe, by the development of the arms and tube-feet and by changing the internal structures. The larval mouth disappears and a new mouth is formed at the centre of the hydrocoel. The permanent anus is formed on the dorsal side.

EXAMPLE OF THE PHYLUM ECHINODERMATA —*ECHINUS*

The genus *Echinus* is a typical example of the class Echinoidea. The name of this animal came from a Greek word *Echinos* meaning hedgehog. The body of Echinus is covered by long spines resembling that of hedgehog, hence the name Echinus. The representatives of the class Echinoidea are generally known as sea-urchins, heart-urchins and sand dollars. They have round or oval bodies and the following description of Echinus will give a general idea of the class.

Habit and Habitat

Echinus is a marine and benthonic animal. They usually live in intertidal zones and may also extend to the depth of about 5000 m. They habitually live in hard or rocky bottoms. They are gregarious forms. They eat all sorts of food available at the bottom of sea. Many small slow-moving and sedentary animals become the victims of Echinus.

External structures

Echinus has a spherical body with a flattened oral surface. The internal structures of the body are housed in a *shell* or *corona*. The corona is overlined by delicate and ciliated *epidermis*. The corona is composed of plates which are firmly sutured

together excepting the two leathery areas, one at the oral side called *peristome* and the other on the aboral side called *periproct* (Fig. 18.10A). The mouth is placed at the centre of the peristome (Fig. 18.10B) and the anus is eccentrically placed in the periproct. The peristome bears five pairs of modified tube-feet called *buccal podia.* They have short bodies with circular disc at the tips and act as the chemo-receptors. Five pairs of small gills project from the peristomial membrane that encircles the mouth.

The corona is composed of twenty meridional rows of polygonal plates. Five perforated areas for two rows of tube-feet are recognised. They are separated by wider areas where such perforations for the tube-feet are absent. In living condition five double rows of tube-feet are distributed in a definite pentaradiate plan from the peristome to the periproct. The areas where the tube-feet are present are called *ambulacral areas* or *radii.* These areas are equally spaced by wider intervening areas between the radii. These areas are called *interambulacral areas* or *inter-radii.* The tube-feet or podia are slender and highly extensible bodies which may project beyond the spines in fully stretched condition.

The corona, as stated earlier, is composed of twenty meridional rows of plates. Each radius at the aboral end terminates in one *ocular plate,* a part of the apical skeleton. In the peristome five pairs of

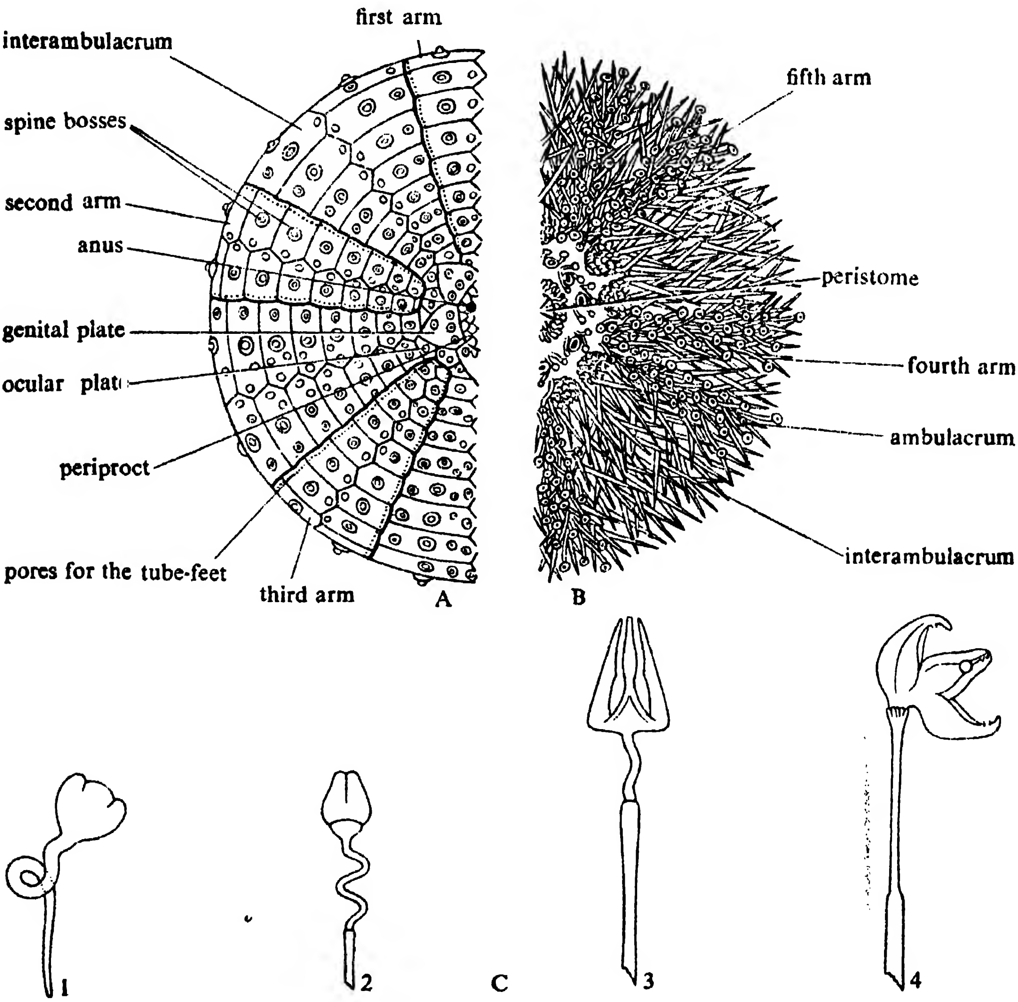


Fig. 18.10. External features of *Echinus*. A. Aboral view (only one half is shown, after removal of spines and pedicellariae). B. Oral view (only one half is shown) of an intact animal. C. Different types of pedicellariae. 1. Trifoliate. 2. Ophiocephalous. 3. Tridactyle and 4. Gemmiform.

small *buccal plates* are present. Two such plates are present in each radius. The periproct also contains a few small irregular plates. Surrounding the periproct there are ten *apical plates*. Of these plates, five are smaller and are called ocular plates while five are larger and are called *genital plates*. On these plates there are tubercles bearing *spines* of various shape and size. Most of the spines are long and cylindrical. The spines are thickly placed all over the body excepting the peristome and periproct. The spines are solid structures and are pointed at the tip. They are movably articulated and have individual muscles to be operated upon.

PEDICELLARIAE. Besides the spines, there are long-stalked three-jawed *pedicellariae*. Several types of pedicellariae are encountered in this group (Fig. 18.10C).

(1) **Gemmiform type,** when the stalk is very stiff and the head is round. Each jaw is provided with poison gland.

(2) **Tridactyle type,** when the stalk is very flexible and the jaws are long.

(3) **Ophiocephalous type,** when the stalk is flexible and the jaws are toothed and broad.

(4) **Trifoliate type,** when the stalk is very flexible and the jaws are blunt and toothed.

SPHAERIDIA. The ambulacral areas contain many small, roundish and transparent solid bodies called *sphaeridia*. These bodies are regarded as the sense organs which are possibly responsible for maintenance of balance.

LANTERN OF ARISTOTLE. The complicated masticatory apparatus of Echinus, is known as *lantern of Aristotle* (Fig. 18.11). It is associated with the mouth and is composed of five strong and sharp teeth whose lower parts are surrounded and supported by the five-sided structures characteristic of the lantern of Aristotle. This structure resembles superficially the ancient Greek lantern. Hence the name is lantern of Aristotle. The lantern comprises of five jaws and five radial pieces called *rotulae* which are joined with the jaws aborally. Each jaw is provided with a tooth. The upward and inward movements of the teeth are caused by the action of the muscles connecting the jaws and the radial arches. The lantern contains coelom as the enlargement of the perihaemal ring.

Body wall

The body wall consists of an *epidermis* on the outer side, a middle layer of *dermis* and an inner lining of *coelomic epithelium*. The epidermis is single-layered and is formed of cuboidal or columnar cells. These cells are ciliated throughout excepting the terminal discs of the tube-feet and other exposed places where the cuticle is present. The dermis is composed of connective tissue with scattered stellate cells and contains endoskeleton. The cells of coelomic epithelium are flattened and flagellated types. Pigment cells (*chromatophores*) are present in or beneath the epidermis. Regular muscular layer is absent and the muscles are limited to the bases of the spines, pedicellariae and the masticatory apparatus.

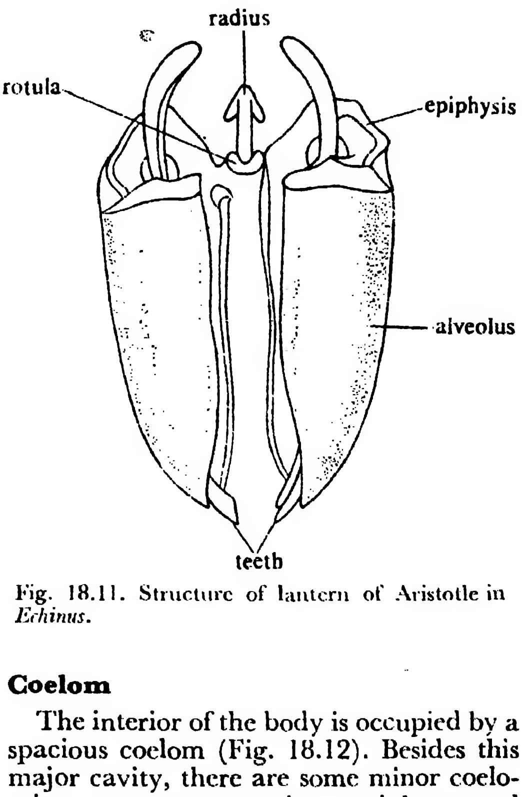


Fig. 18.11. Structure of lantern of Aristotle in *Echinus*.

Coelom

The interior of the body is occupied by a spacious coelom (Fig. 18.12). Besides this major cavity, there are some minor coelomic compartments, viz. peripharyngeal cavity, periproctal sinus, perianal sinus and aboral or genital sinus. These compartments are either completely or partly cut off from the main coelom.

The coelom is filled with coelomic fluid which is similar to sea water in composition and contains usual coelomocytes. A few types of coelomocytes are recorded in

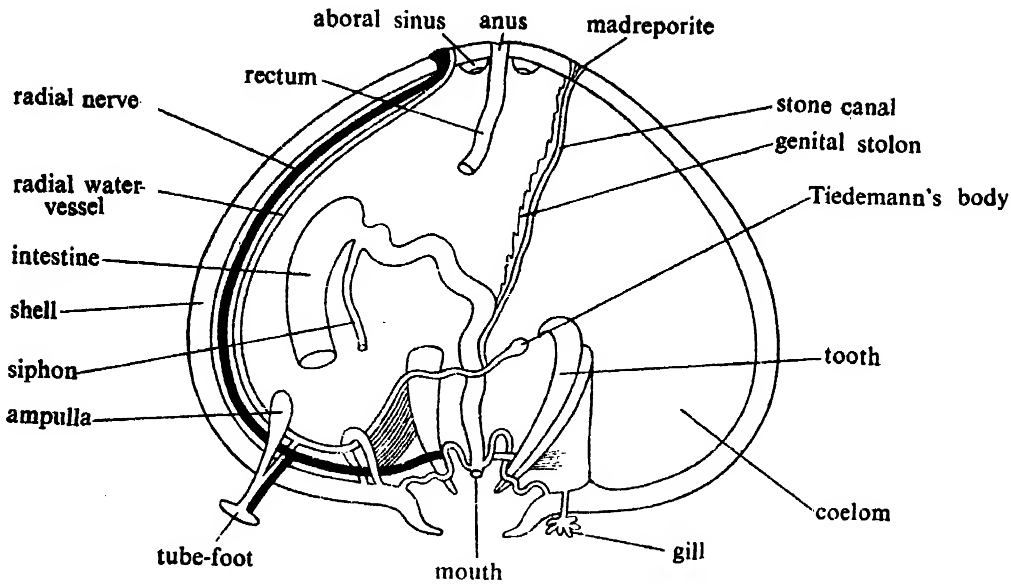


Fig. 18.12. Diagrammatic vertical section of *Echinus* showing internal organs. Note that a portion of the alimentary canal is removed.

echinoids. Coelomocytes with pointed or broad pseudopodia are phagocytic in function and the types containing different coloured spherules have no phagocytic power. The small and rounded variety with a vibratile flagellum is regarded to be disquamated cells from the coelomic epithelium. These cells lose flagella and become transformed into amoeboid coelomocytes. The relative frequency of these different coelomocytes also varies greatly in different forms.

Digestive system

The mouth is situated at the centre of the oral surface of the body and is encircled by a lip-like membrane, the peristome. The mouth leads into a buccal cavity from which originates the oesophagus. The alimentary canal is looped.

The oesophagus is slender and leads into the flattened stomach. A short caecum arises from the junction of oesophagus with the stomach. Extending from the beginning of the stomach up to the beginning of the intestine runs a slender tube called *siphon*. The inner wall of the siphon is ciliated and a constant flow of water current passes from the anterior to the posterior direction of the siphon. By the removal of excess water through the siphon the food matters become concentrated in the stomach for digestion. The intestine ascends as the narrow rectum which opens to the exterior through the anus on the aboral side. In the digestive system of Echinus and in many sea-urchins there are many commensal ciliates and parasites. Besides them, many other commensals and parasites are recorded inside or outside the body.

Histological picture of the alimentary canal shows the following layers: (1) The outermost layer is covered by flagellated coelomic epithelium. (2) The next inner layer is composed of a very thin muscular layer (mostly circular muscles). (3) Beneath the muscle layer lies a connective tissue layer. (4) The innermost layer lining the lumen of the alimentary canal comprises of slender columnar ciliated epithelium. Gland cells are also present in this layer except in the intestine where the gland cells are reported to be wanting.

Respiratory system

The respiratory system consists of five pairs of small, branched and thin-walled outgrowths of the body at the margin of the peristome. These are called *peristomial gills* or *branchiae*. Each interambulacral area contains one pair of gills, one on each side. The lumen of the gills is continuous with the peripharyngeal coelom. Besides these peristomial gills, five dental sacs are located on the top the lantern of Aristotle.

The tube-feet and the siphon help in respiratory process.

Water vascular system

The water vascular system is fundamentally similar to that of Asterias. The main *ring canal* bears five small inter-radial *Tiedemann's bodies*. The stone canal is membranous and is not calcified. Each radial canal gives a branch to the buccal podia and terminates as the lumen of the terminal tentacle. The axial sinus becomes enlarged under the madreporite to form an ampulla into which the stone canal opens.

Haemal system or Blood lacunar system

The haemal system includes an *oral haemal ring* round the oesophagus and five *radial haemal sinuses*. The radial haemal sinuses end blindly at the aboral side.

Locomotion

Numerous elongated double rows of tube-feet, projecting from the ambulacral areas, are the principal locomotor organs. The mechanism of movement by the tube-feet is similar to that of Asterias. As because the arms are lacking in Echinus, the tube-feet become greatly extended towards the direction of movement. Besides the tube-feet, the animal can also move by using the spines.

Excretory system

There is no definite excretory organ in Echinus. The nitrogenous wastes are extracted and eliminated through the entire surface of the body.

Nervous system

The nervous system of Echinus, consists of a *nerve ring* surrounding the mouth and five *radial nerves* which extend up to the terminal tentacles. The radial nerves are enclosed by *epineural canals* and innervate the tube-feet, spines, pedicellariae, so-called 'eye' and sphaeridia. The circum-oral nerve ring together with the radial nerves constitute the ectoneural nervous system. The hyponeural and coelomic nervous systems are extremely ill-developed.

Sense organs

The sense organs are not specialised. As stated earlier, the sphaeridia, distributed in the ambulacral areas, are the organs of balance. There are five so-called 'eyes' (pigmented nervous cushions, one on each ocular plate near the terminal tentacle) which are regarded as photoreceptors.

Reproductive system

Echinus is a dioecious echinoderm and sexual dimorphism is absent. The gonads are five in number. They are large, branched, racemose glandular masses in the perivisceral cavity. The *testes* or *ovaries* are more or less similar in appearance and become voluminous at matured state. The gonads develop as the outgrowths of the genital rachis which becomes atrophied in adults. Each gonad at its aboral end gives a short *gonoduct* which opens to the exterior through *gonopore*. There are five gonopores, one on each genital plate. After maturation, the gametes are set free in the sea water and the fertilization is external.

Development

The prelarval developmental stages are similar to that of Asterias. The larva in Echinus is called the Echinopluteus which is described in the general notes of this chapter. This larva in course of development metamorphoses into a miniature round Echinus.

Example of the Phylum Echinodermata —*HOLOTHURIA*

Holothuria is a typical representative of the class Holothuroidea. This class includes a large number of sausage-shaped forms popularly called sea-cucumbers. The widely distributed genus of the class, *Holothuria*, is described here to get an idea of the anatomical construction of the group.

Habit and Habitat

Holothuria usually lives in sandy bottom of the sea and may remain partially buried in the sand. They are also found at all depths of the sea, ranging from the shallow to deep water. They are very sluggish by nature. They feed on organic particles present in sand or other minute living organisms.

External structures

Holothuria has an elongated body with greatly elongated oral-aboral axis (Fig. 18.13). The oral end is provided with *mouth*. The *anus* is situated at the opposite

end. The mouth is surrounded by a thin peristomial membrane which is bordered by a row of branched *tentacles*. The tentacles are provided with circlet of short

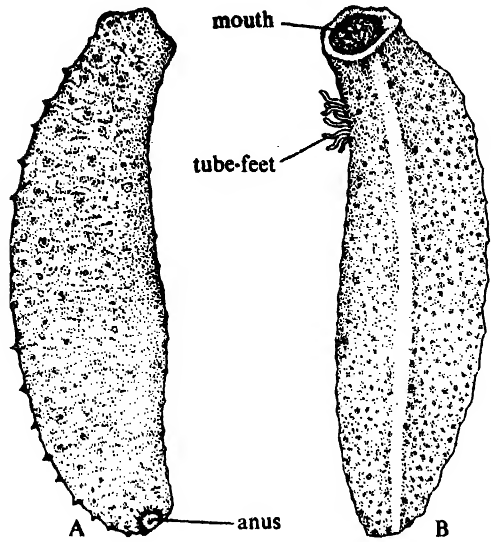


Fig. 18.13. External features of *Holothuria*. A. Aboral view. B. Oral view.

terminal branches which again branch and become shield-shaped in appearance. The tentacles are retractile into the *ampullae*. The shield-shaped tentacular branches are characteristics of the genus.

The radial symmetry of the body has become replaced by bilateral symmetry. The 'dorsal' and 'ventral' sides can be distinguished. The 'ventral' side is more or less flattened and possesses three *radii* opposite to the madreporic interradius with its two radii. In other forms the tube-feet are arranged along the radii from the oral to the anal end of the body, but in Holothuria, the radial orientation of the tube-feet is obliterated and they spread over the *inter-radii* of the body. But the internal structures retain their radial disposition.

Body wall

The histological picture of the body wall reveals the presence of a thin *cuticle* over a non-ciliated *epidermis*. There are numerous small ossicles in the *dermis*. There are longitudinal muscle-bands under the radii and transverse muscle-bands between the radii. There is a thin layer of ciliated coelomic epithelium lining the internal side of the body wall.

Coelom

The perivisceral coelom between the alimentary canal and the body wall is quite well-developed. The coelom is filled with coelomic fluid containing various types of *coelomocytes*. One of the types of the coelomocytes, called *haemocytes* contain red pigment, the haemoglobin. The other types of coelomocytes include: (i) lymphocytes, (ii) phagocytes, (iii) coloured and colourless morula cells, (iv) fusiform cells, (v) crystal cells, (vi) vibratile cells, etc.

Digestive system

The mouth leads into a short *oesophagus* which in turn opens into a muscular *stomach* (Fig. 18.14). The oesophagus is

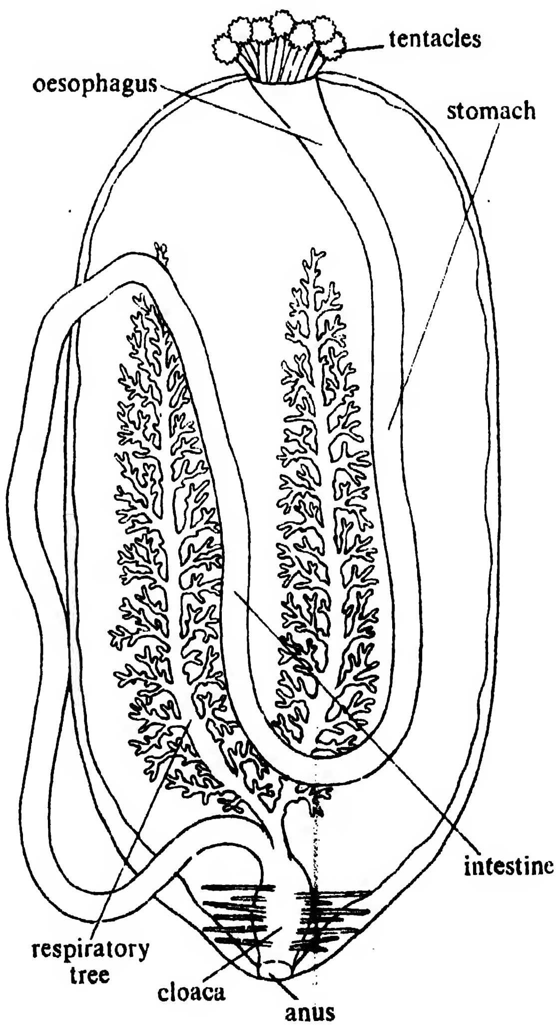


Fig. 18.14. Digestive system and respiratory trees of *Holothuria*. Note that the calcareous ring around oesophagus is removed.

enclosed by a calcareous ring which is composed of five radial and five inter-radial ossicles. The stomach is joined with the thin-walled coiled *intestine*. The intestine is much longer than the body length and becomes coiled. The posterior part of the intestine is connected to a muscular *cloaca* by short *rectum*. The cloaca is supported by remnants of mesenteries which are called *cloacal suspensors*. The rectum opens to the exterior through the anus.

Respiratory system

There are two long and elaborately branched *respiratory trees* which open into the cloacal chamber. The terminal branches end in thin-walled ampullae. Through the wall of the ampullae, water from the cloaca, can pass into the coelom and thus help in conveying oxygen to the coelomic fluid and to other organs. In Holothuria, the lower branches of the respiratory trees are converted into tubes called *Cuvierian organs*. These tubules can be everted through the anus and they produce a sticky secretions so as to entangle the enemy or to retard the entry of enemies by liberation of toxin.

Water vascular system

The water vascular system comprises of an *oral ring vessel* which in turn gives off five *radial vessels*. Each radial vessel supplies branches to the tentacles anteriorly and passes posteriorly along the ambulacral areas to give branches to the tube-feet (Fig. 18.15). Each tube-foot has an ampulla. The oral ring vessel is provided with a single large *polian vesicle* and one or more stone canals which communicate with the anterior of the coelom by perforated extremity of the madreporite canals. The madreporite is internally placed. The *axial sinus* is very small.

Haemal system or Blood lacunar system

The haemal system is quite well-formed in Holothuria. This system consists of a *circum-oesophageal haemal sinus* which gives five *radial haemal vessels* at the anterior side. Posteriorly, the circum-oesophageal haemal sinus gives two *haemal sinuses* to the alimentary canal which send numerous smaller branches to the intestine.

Locomotion

Like other echinoderms, Holothuria move by the *tube-feet* or *podia*. The mechanism of movement is same as that in Echinus and Asterias.

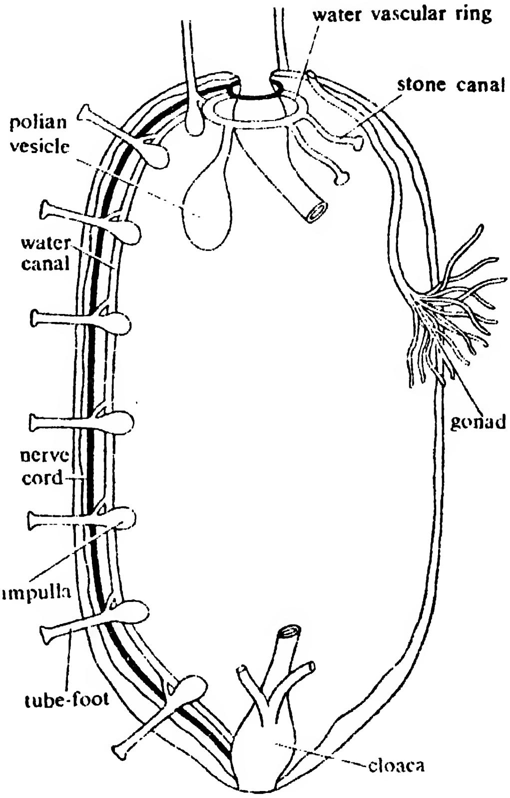


Fig. 18.15. Water vascular system, nervous system and gonad of *Holothuria*. Water vascular system and nervous system are drawn only on one side.

Excretory system

There is no specialised organ in Holothuria to act as excretory organ. The nitrogenous waste products are extracted by the cloacal wall and are eliminated to the exterior through the anus. The respiratory trees are also reported to play some role in excretion.

Nervous system

The nervous system is represented by a *circumoral nerve ring* beneath the peristomial membrane. Five *radial nerves* emerge from the oral nerve ring along the ambulacral areas.

No special sense organ is present in Holothuria, excepting the tentacles which act as tactile organs.

Reproductive system and Development

The sexes are separate. There is a single gonad in each sex consisting of a tubular follicle situated in the 'dorsal' interradius. The gonad has a gonoduct which opens to the dorsal surface of the oral end. The *testis* and *ovary* look alike. The cord-like *genital stolon* represents the axial organ of the genus. Fertilization is external and the prelarval developmental stages are similar to that of Asterias and Echinus. The larval form is known as *Auricularia*. The larval mouth persists in the adult. The detailed account of the larval form is described in the general notes on the phylum.

EXAMPLE OF THE PHYLUM ECHINODERMATA —*OPHIURA*

Ophiura is a typical example of the class Ophiuroidea. The members of this class are generally called brittle stars or serpent stars. All the ophiuroids have a basic structural construction and the description of the genus, *Ophiura*, will give a general idea of the group.

Habit and Habitat

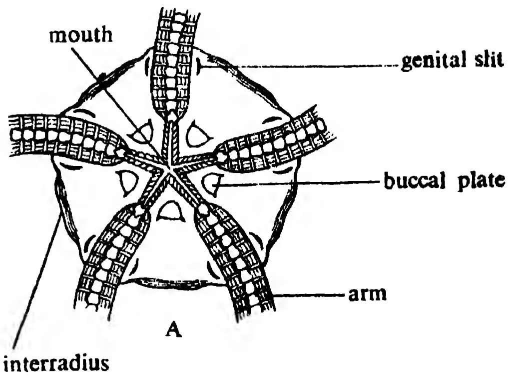
Ophiura usually lives in shallow to deep water of the ocean. They usually hide themselves at daytime beneath the sea-weeds or stones. They can also burrow in the sand or mud. They are very active at night. They can move quite rapidly by their arms. They are carnivorous animals and devour small crustaceans, worms and other small animals.

External structures

The body of Ophiura consists of a star-shaped disc and five highly flexible arms (Fig. 18.16). The arms are elongated, slender and fragile. The arms are sharply marked off from the disc. The arms are unbranched in Ophiura, but in *Gorgonocephalus* the arms are extensively branched. Like that of Asterias, mouth is situated at the centre of the oral surface and the oral-aboral axis is very short. The mouth is pentagonal and at each interradius, there is a more or less triangular projection called *oral papilla* or *jaw*. The *madreporite* is situated in an inter-radius on the oral surface. The ambulacral grooves and the anus are absent. The pedicellariae are wanting and the *spines* are located on the lateral plates of the arms.

Body wall

The integument is non-ciliated and is covered by *cuticle*. The epidermis is vestigial and the dermis is devoid of muscles.



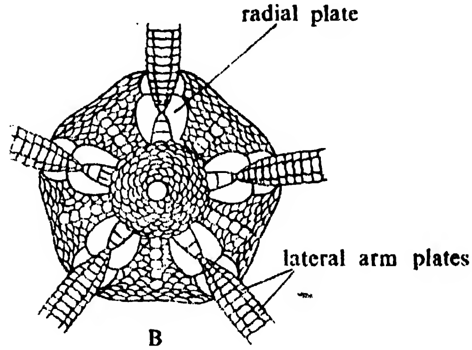


Fig. 18.16. External features of *Ophiura*. A. Oral view. B. Aboral view. Only the central part of the body is drawn.

Skeleton

The skeleton is well-developed in Ophiura. Each arm consists of similar segments and the interior of each segment is almost filled with solid skeletal blocks called *vertebral* or *ambulacral ossicles* (Fig. 18.17). The outer side of the arms contains four rows of plates—two lateral, one aboral and one oral. Two radial plates or shields, one on each side of the arms, are present. The centre of the aboral side of the disc is occupied by a large roundish *central plate* which is surrounded by many *concentric plates*. In the oral side, the mouth is surrounded by five large *oral* or *buccal plates* and five pairs of aboral plates along the inter-radial planes of the disc. One of the oral plates is perforated and acts as madreporite. The oral papillae contain a few small plates.

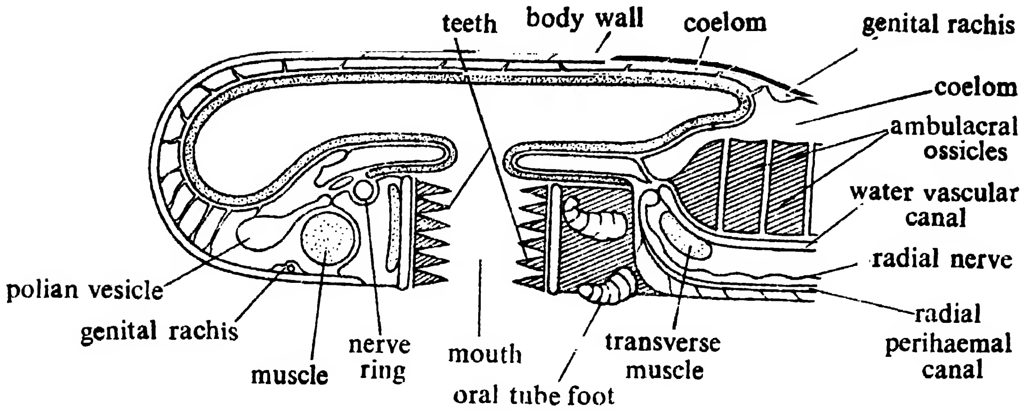


Fig. 18.17. Diagrammatic section of *Ophiura*, passing through an inter-radius on the left side and a radius with a part of the arm base.

Coelom

Like all other echinoderms, the *coelom* in Ophiura is enterocoelic in origin. The *perivisceral coelom* is quite spacious and is traversed by *mesenteries* which run between the body wall and the viscera. In the arms the coelom is restricted to a small and crescentic space on the aboral side of the vertebral ossicles. The coelomic fluid contains *coelomocytes*. The coelomocytes are granular and contain fine pseudopodia which anastomose to form networks. The spheroid coelomocytes recorded in the axial gland suggest the fact that the coelomocytes are formed in this gland.

Digestive system

The alimentary canal is present inside the disc. As described earlier, the *mouth* is placed at the centre of the oral side and is surrounded by five groups of movable plates serving as *jaws*. Many spines are extended over the mouth which act as strainer. The mouth leads into a very short *oesophagus* which opens into the *stomach*. The stomach is sac-like, non-protrusible and is attached with the body wall by mesenteries. Lack of anus, caeca and intestine are quite striking in the digestive system of Ophiura.

Respiratory system

Along the sides of the arm bases, there are five pairs of sac-like invaginations on the oral surface called *bursae*. Each bursa is supported by genital shields and opens by a slit-like aperture. The bursae occupy the spaces between the stomach pouches. The bursae inside the disc coelom fuse at places. The wall of the bursa is histologically same as the body wall, but the dermis is very thin. Through the bursae a constant flow of water current is maintained which possibly helps in the process of respiration.

Water vascular system

The water vascular system is almost similar to that of Asterias, but exhibits certain minor peculiarities. The madreporite is usually one in this genus, but in *Ophiactis virens*, five madreporites are present. The axial complex is highly developed. The axial sinus encloses the axial organ and the stone canal (Fig. 18.18). The wall of the stone canal lacks calcareous matter and opens to the exterior through the pore canal. These structures are shifted towards the oral side. The Tiedemann's bodies appear to be wanting, but in *Ophiacten sericeum* and *Gorgonocephalus*, such structures or their equivalents are reported to be present. The radial canals run through the substance of the vertebral ossicles as the cavity of the terminal tentacles. The lateral branches to the tube-feet from the radial canals are very short. They lack suckers and ampullae. The tube-feet are sensory in function and have nothing to do with locomotion.

Haemal system or Blood lacunar system

The haemal system is quite well-developed in Ophiura. The oral and aboral haemal channels are disposed in the similar fashion as seen in Asterias. The haemal channels are very shallow.

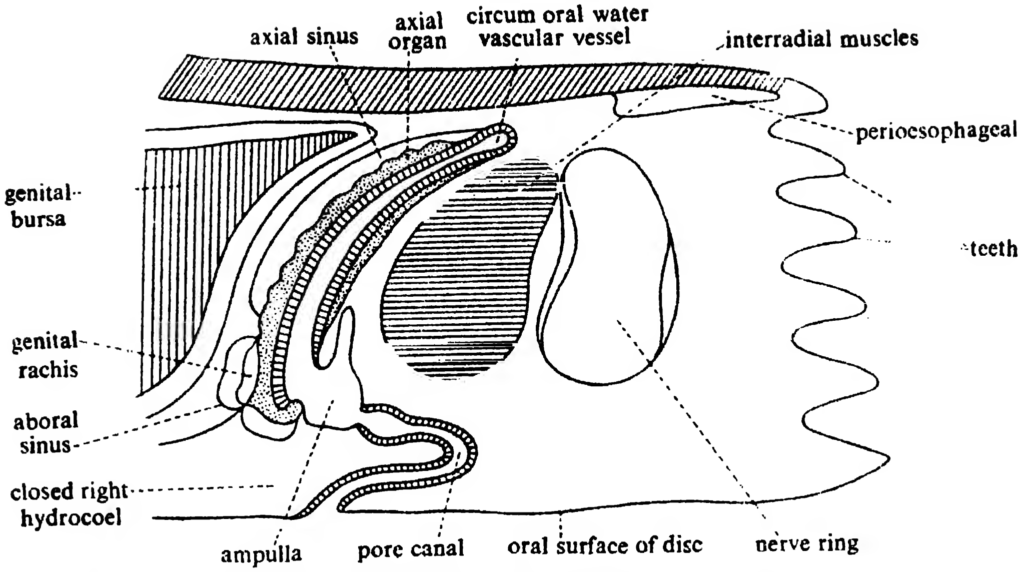


Fig. 18.18. Vertical section (diagrammatic) of *Ophiura* passing through the madreporitic inter-radius.

Locomotion

The tube-feet, as described earlier, have nothing to do with locomotion. The movement is affected by the highly flexible arms. During locomotion the disc of the body is lifted from the substratum with the help of the arms. By the action of the arms, Ophiura in this state, can move at considerable speed. The arms also help the animal to swim in water.

Excretory system

There is no special excretory organ in Ophiura. The excretory products pass out of the body through the bursal wall. The excretory products in the form of black or yellow spherules are seen to be accumulated in the bursal wall.

Nervous system

The nervous system like that of Asterias comprises of *circumoral nerve ring* and the *radial nerves* to the arms. The radial nerves bear ganglionic swellings, one at each vertebral ossicle of the arms and terminate at the base of the terminal tentacles.

There is no special sense organ in Ophiura. The tube-feet are sensory in function.

Reproductive system

The sexes are separate and sexual dimorphism is absent. The gonads are sac-like which remain attached with the bursae and open into them. The bursae are ten in number and open to the exterior through slit-like apertures, situated one on each side of the base of the arms. The matured gametes are discharged into the cavity of the bursae and from there the gametes are expelled to the exterior through the bursal apertures. For this particular function, the bursae are generally called *genital bursae*.

Fertilization and Development

Fertilization is external. The prelarval developmental stages are similar to that of Asterias. The particular larval form encountered in Ophiura is *Ophiopluteus*. The detailed structural organisation of ophiopluteus is described separately in the general notes on this phylum. The ophiopluteus, after some days, metamorphoses into the adult.

Example of the Phylum Echinodermata —*ANTEDON*

Antedon is a very common genus of the class Crinoidea. They are commonly called feather-stars or sea-lilies. The genus, *Antedon*, is described below as because it is a typical representative of the group.

Habit and Habitat

Antedon is an inhabitant of the shallow water. It is a stalked form at the beginning

and with the attainment of adulthood it breaks off from its stalk and swims about actively by the arms. They can also cling to the substratum by the cirri. They are gregarious forms and feed on microscopic living organisms.

External structures

The body of Antedon is composed of small central part, called *calyx* from which elongated slender *arms* radiate. (Fig. 18.19). The arms are actually five in number and each arm is bifurcated at the basal end. So the number apparently comes to ten. Each arm bears double rows of alternate small branches called the *pinnules* (Fig. 18.20A). The aboral side of the calyx is convex and the oral side is flat. On the aboral side the calyx bears a knob-like structure which is the stung of the stalk. The knob is composed of *centrodorsal ossicle* which is provided with many-jointed *cirri* (Fig. 18.21). Each cirrus terminates in a small hook-like claw which help in temporary attachment. The oral surface is lined by a leathery tegmen and bears the mouth at the centre. The mouth is surrounded by *tube-fa?t* or *podia* which are sensory in function. The podia are beset with sensory papillae. The *anus* is situated on a papilliform projection in one of the inter-radii on the oral surface. Radiating from the mouth there are five *ambulacral grooves* across the tegmen. In the mouth region the ambulacral grooves are separated by five *oral valves*. Each groove runs into one of the pairs of arms and gives branch to each pinnule. There are, in all, ten grooves—supplying ten arm-branches. The grooves throughout the course bear finger-like non-prehensile tube-feet or podia. The ambulacral grooves are actually the food grooves in Antedon.

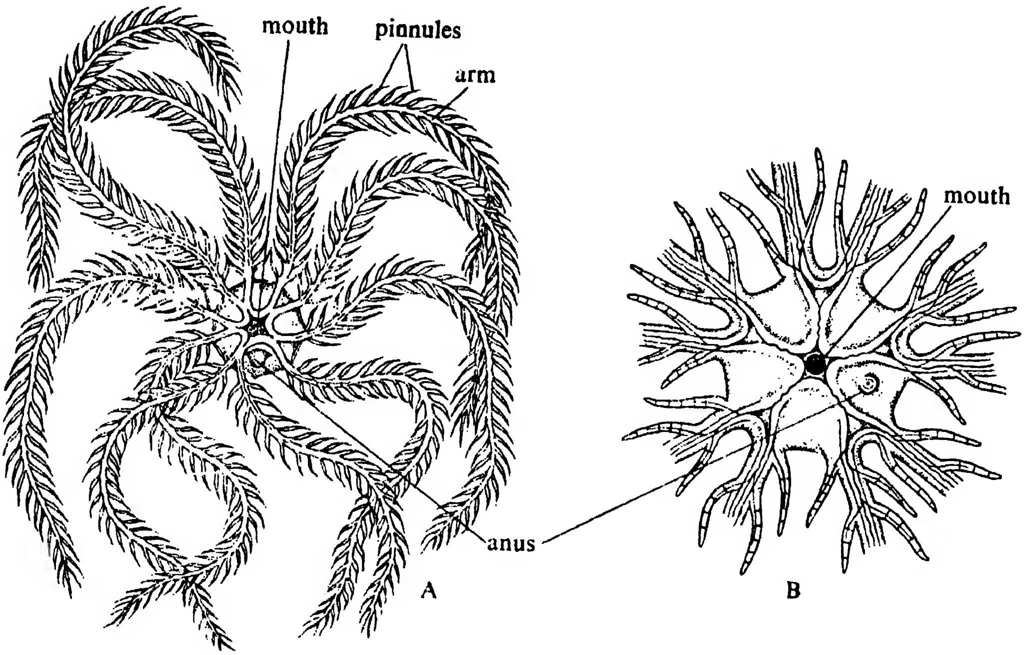


Fig. 18.19. External features of *Antedon*. A. An entire animal. B. Enlarged oral side of the central disc.

The ambulacral grooves and the podia are ciliated. They help to convey food particles to the mouth which are gathered from the water current set by the cilia.

Body wall

The ectoderm is rudimentary except at the ambulacral grooves. The basement membrane is absent. The dermis is leathery at the oral side. The body is covered by a delicate cuticle.

Skeleton

The skeletal elements, specially on the aboral side, are well-formed. The aboral skeleton comprises of the large pentagonal *centrodorsal ossicle*, a thin plate called

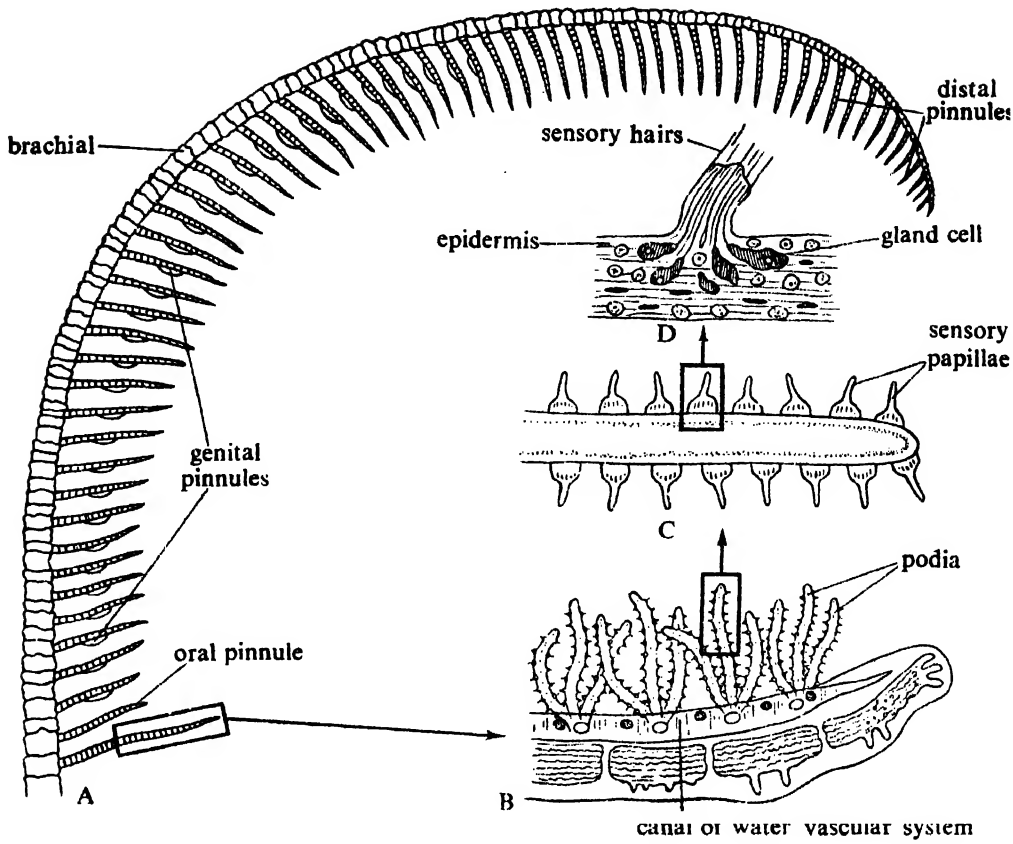


Fig. 18.20. Detailed structural organisation of an arm of *Antedon*. A. Single arm. B. Enlarged view of the end of a pinnule showing podia. C. A podium with sensory papillae. D. Sectional view of a sensory papilla to show its internal structure.

the *rosette* (formed by the coalescence of the larval pieces called basals). It lies internally and remains concealed by the centrodorsal ossicle. The other components are three *radial ossicles* (first radial ossicle, second radial ossicle and the third radial ossicle) in each radius, a row of *brachial ossicles* in each arm, a row of ossicles in each pinnule, and a row of *cirral* ossicles in each cirrus. The skeletons particularly in the appendages are movably placed one upon the other.

Coelom

The perivisceral coelom in the calyx contains numerous *trabeculae*. Surrounding the oesophagus there is a vertical coelomic space, called *axial sinus*. The axial sinus and other coelomic spaces are continued into the arms. At the aboral side of the axial sinus, the coelom is represented at the centre by a characteristic *chambered organ* (Fig. 18.22A). The chambered organ is composed of five symmetrically placed coelomic cavities around a central axis. Each arm contains four coelomic canals (a pair of *subtentacular* canals, a small *genital* canal and a minute *coeliac* canal). All these canals emerge from the perivisceral cavity. The perivisceral cavity communicates with the exterior through numerous ciliated *water-pores* on the oral surface. Two types of coelomocytes are recorded in Antedon. They are: (*a*) an amoeboid type with short pseudopodia and phagocytic in function and (*b*) an elongated form containing rods and granules. However, Cuenot (1891) found both coloured as well as colourless morula cells in *Antedon rosocea*.

Digestive system

The mouth is situated at the centre of the oral side (*endocyclic* condition). The mouth opens into a short vertical funnel-like *oesophagus*. The oesophagus leads into a wide *stomach*. The stomach is curved along the axis. The intestine bears a number of small blunt pouches and

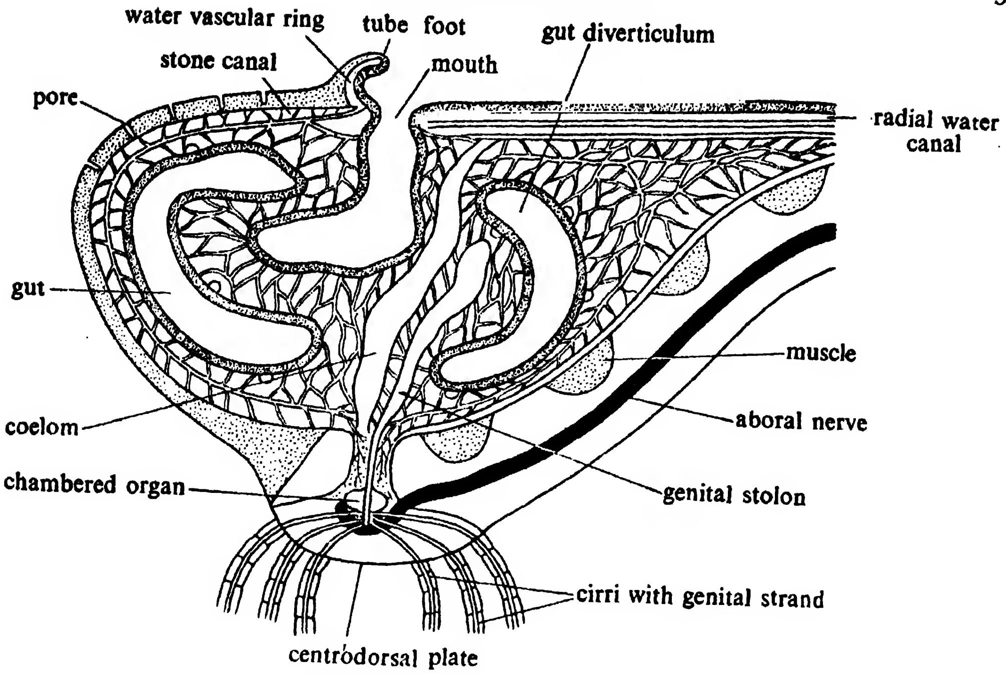


Fig. 18.21 Sectional view (diagrammatic) of *Antedon* passing through the central disc and the base of an arm.

two long branched diverticula called *hepatic caeca*. The stomach opens distally into a short intestine which proceeds as *rectum*. The rectum passes upwards to the excentrically placed *anus*. The alimentary canal, excepting the germinal portion of the rectum, is ciliated.

Respiratory system

There is no specialised organ for respiration in Antedon. The tube-feet lack terminal suckers and help in respiration. Besides the tube-feet, the rectum is capable of rhythmical contraction. Due to the ability of contraction and expansion, water is drawn in and driven out from the rectum through the anus. This method of taking in and ejecting out of water is possibly associated with the process of respiration.

Water vascular system

The water vascular system is not so pronounced in Antedon. The water vascular system lacks direct communication with the exterior. The water vascular ring encircles the mouth and gives off many short stone canals which open to the perivisceral cavity. The perivisceral cavity communicates with the exterior through numerous ciliated water-pores. The ampullae are absent but the wall of the water canals is slightly contractile due to contractility of the muscular strand. There is a series of radial vessels running beneath the ambulacral grooves which give branches to the pinnules. A series of podia or tube-feet without terminal suckers are present. They are tactile organs and help in respiration.

Haemal system or Blood lacunar system

This system is made up of intercommunicating spaces in connective tissue trabeculae. It consists of a plexus of large lacunae, *perioesophageal plexus* round the oesophagus. This is connected with a *subtegmental plexus* under the tegmen. A special organ (related to the axial gland) called *spongy organ* receives branches from the perioesophageal plexus on the aboral side. The spongy organ (designated as *labial plexus* in earlier accounts) is made up of mostly rounded cells and possibly manufactures the coelomocytes. The haemal system contains a colourless proteinaceous fluid with few cells.

Locomotion

The tube-feet in Antedon have nothing to do with locomotion. It can move very slowly by its cirri. It can also swim by the undulation of the arms.

Excretory system

Antedon lacks definite excretory organ. The actual nature of excretory products and the process of elimination are not clearly known. It is reported that the excretory products are accumulated in the coelomic lining. The coelomocytes help in the transportation of the excretory products of the body.

Nervous system

The nervous system is divisible into three types: (*a*) *Aboral* or *entoneural* system, (*b*) *Deeper oral* or *hyponeural* system and (*c*) *Oral* or *ectoneural* system. Of all these systems, the entoneural system is well-developed (Fig. 18.22B). This system comprises

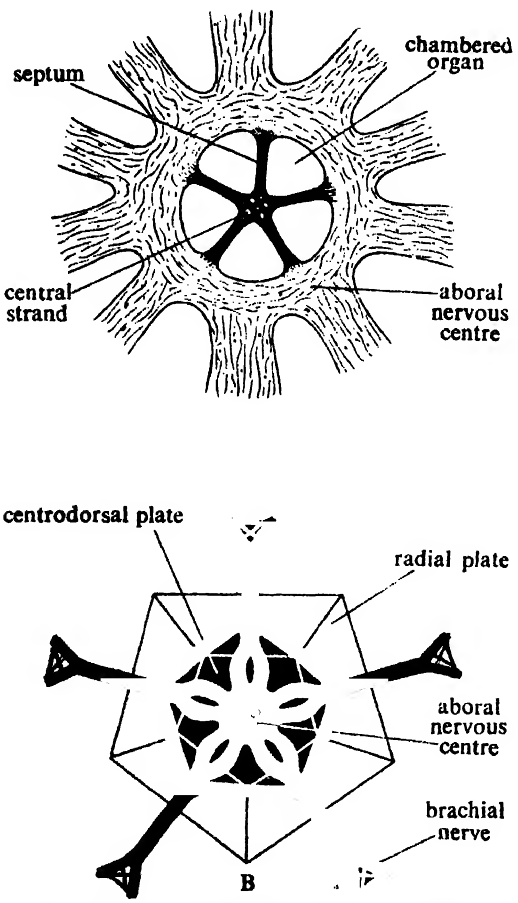


Fig. 18.22. A. Chambered organ of *Antedon* (sectional view). B. Aboral nerve centre of *Antedon*.

of a cup-shaped *nervous mass* situated at the apex of the cavity of the calyx. This nervous mass gives off five stout inter-radial *brachial nerves* to the five primary arms which are united by a *nerve pentagon* situated in the radial plates of the calyx. Each brachial nerve divides into two parts which are again connected by direct and decussating commissures. The brachial nerves bear ganglionated swellings with bipolar and multipolar nerve cells. The brachial nerves give branches to the flexor muscles and adjoining epidermis, aboral part of the arms and pinnules. The deeper oral or hyponeural system comprises of a nerve pentagon lodged in the connective tissue of the tegmen. The nerves emerging from the nerve pentagon innervate the tegmen, anal tube and other internal organs. Of these nerves, ten main branches go to the ten arms and innervate the musculature of the water vessels and pinnules. These nerves are connected with the aboral nervous system. The ectoneural or superficial or oral nervous system consists of a superficial nerve ring surrounding the mouth which gives radial nerve cords. The radial nerve cords run in the ambulacral grooves of the arms and pinnules. These nerve cords consist of nerve cells and longitudinal nerve fibres and supply the ambulacral epidermis, inner surface of the tube-feet and the adjoining areas.

Sense organs

There exists no special sense organ in Antedon. The papillae present on the tube-feet are both sensory and secretory in function. Each papilla comprises a slender epidermal projection with sensory bristles and basal glandular cells (Fig. 18.20D). The papillae are possibly the tactile organs.

Reproductive system

The sexes are separate and sexual dimorphism is absent. The axial organ is continuous with a circular *genital rachis* which in turn gives *genital cords*. The genital cords pass into the *genital canal* and reach the pinnules where they become differentiated into the *gonads*. The genital tube, very common in other crinoids, is absent in this form. The genital system is enclosed by a plexus of haemal system. When the gametes become mature, they escape to the exterior by the rupture of the pinnule wall. After the rupture of the pinnule wall, the eggs remain attached with the pinnule by secretion of cement glands.

Fertilization and Development

The fertilization is external. The zygote after the routine developmental processes is transformed into a free-swimming barrel-shaped ciliated larva, *Antedon* larva. This larva is also called *Doliolaria* larva of Haeckel. After a brief free-swimming phase, the larva fixes itself by a stalk to the substratum. The fixed stage is called the "*Pentacrinoid*" larva which is transformed into an adult Antedon in due time. The details of the larval forms have been dealt separately in the last part of this chapter.

SOME INTERESTING ECHINODERMS

A brief note on some of the interesting members of echinoderms is described below to give an idea about the structural diversities of the phylum.

Astropecten

Astropecten is a widely distributed starfish. They inhabit sandy bottom of sea where they can burrow. *Astropecten polycanthus* remains buried in sand most of the time and comes out twice a day in search of food—once in the morning and once in the evening. The genus Astropecten is consisted of about 100 species. The body consists of a flattened five-pointed disc with short arms. There are rows of spines bordering the arms (Fig. 18.23). The infra-marginal plates are elongated and meet the adambulacrals to form the oral surface of the arms. The pedicellariae are either sessile or pectinate types. The conical tube-feet are devoid of suckers and possess circular muscles. The ampullae are bifurcated. The speed of locomotion is recorded in some forms of this genus. *Astropecten auranciacus* moves 30–60 cm per minute and *Astropecten spinulosus* moves 60 cm per minute. The mouth is very wide, distensible and can swallow the prey (bivalves, snails, crustaceans, annelids) very easily. The stone canal is extremely complicated due to extensive development of the internal ridge. The ridge divides the stone canal into two tubes, each of which, contains a pair of scrolls. Two to four polian vesicles are given in each inter-radius. These vesicles emerge from a common stalk (Fig. 18.29). The optic cushion lacks pigment cup and the retinal cells are distributed throughout the optic cushion. The brachiolaria larva stage is absent.

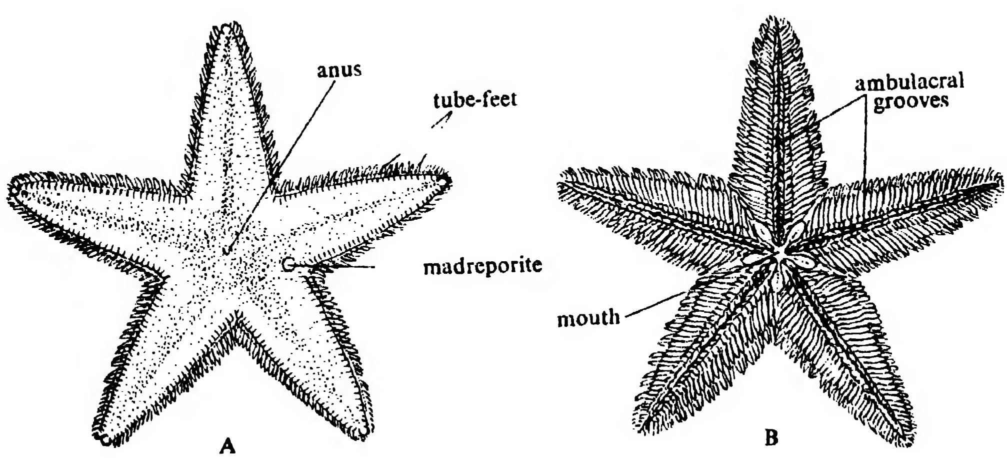


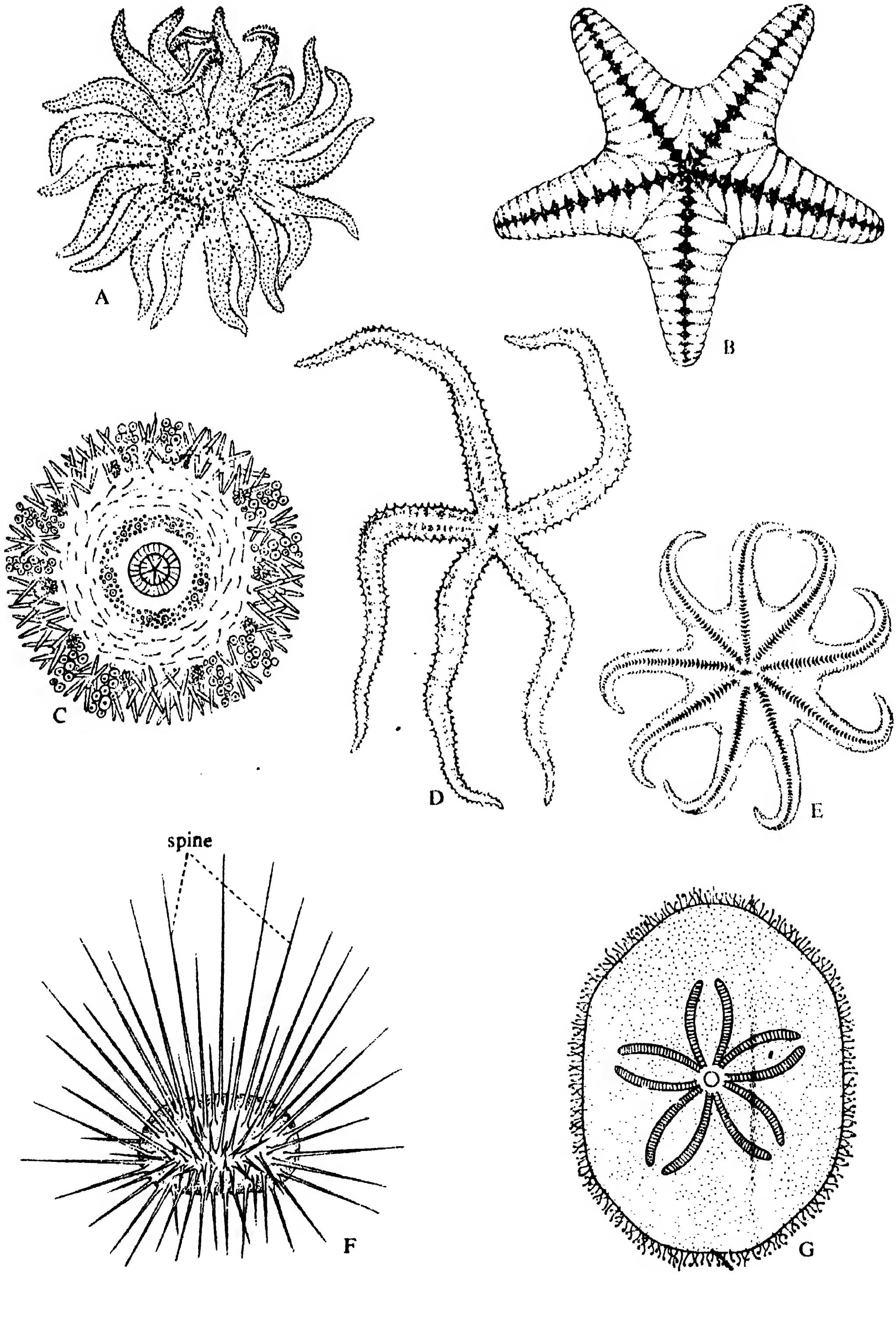
Fig. 18.23. External features of *Astropecten*. A. Aboral view. B. Oral view.

Heliaster

Heliaster (Fig. 18.24A) is the single genus of the family, Heliasteridae. The genus contains a few species and lives in shallow water of the Panamic region. The body consists of a very broad disc with numerous short tapering arms. The number of the arms vary from 20 to 44. Clark (1907) has shown that Heliaster starts its life with five arms and additional arms are added in all the inter-radii excepting the inter-radius containing the madreporite. Only one madreporite is present. The skeleton is of reticulate type. The pedicellariae are straight and crossed types. The disc coelom and the brachial coelom are almost separated by a circular vertical wall with which the interbrachial septa are joined by their inner ends.

Zoroaster

Zoroaster (Fig. 18.24D) is the typical genus of the family Zoroasteridae. It inhabits the deep sea. The body consists of a small disc with five elongated slender arms. The pedicellariae are of straight type. The aboral side of the body contains small spines with small papular zones. Usually four rows of tube-feet are present in each ambulacral groove.



Ctenodiscus

Ctenodiscus (Fig. 18.24B) is a typical genus under the family Goniopectinidae. The members of the genus are generally muddwellers. The body is stellate-shaped andthe marginal plates are very prominent. The cribiform organs (a cavity containing lamellae and bounded by marginal plates) are very simple in organisation. The alimentary canal lacks intestine, intestinal caeca and anus. An epiproctal cone is present.

Porcellanaster

Porcellanaster (Fig. 18.25C) is the typical example of the family Porcellanasteridae. The representatives of the genus are mud-dwellers and live at considerable depths. The body consists of star-shaped disc and five narrow pointed arms. The arms are bordered by thin marginal plates. The aboral side is membranous with a central elevation called epiproctal cone. The alimentary canal lacks intestine, intestinal caeca and anus. The tube-feet are pointed and lack suckers. The ampullae are simple. In each interradius single cribriform organ is present.

Luidia

Luidia is the only genus under the family Luididae and has about 42 species. This genus is distributed in the tropical and subtropical regions. The body consists of a very small disc with elongated flexible arms. Most of the species possess five arms and others may have six to eleven arms. The arms are bordered by spines. The papulae are branched. The anus and the intestinal caeca are absent. The pedicellariae are usually present.

Solaster

Solaster (Fig. 18.24E) is a typical multirayed sun-star belonging to the family Solasteridae. The body consists of a very broad central disc and 7–14 short tapering arms. The aboral skeleton is reticulate type and contains groups of small spines.

Clypeaster

Clypeaster (Fig. 18.24G) is the only surviving genus of the family Clypeasteridae. They are distributed in the tropical and subtropical regions of the earth and inhabit the sandy bottom. They are commonly called sand-dollars. The test is more or less round in outline and is covered with thick short spines. The madreporite is placed at the centre of the aboral side from which radiate five petaloid ambulacral areas. There are five simple grooves along the centre of the ambulacral areas. At the beginning of each ambulacral area near the peristome there exist two sphaeridia. The sphaeridia are devoid of nerve ring and are not movable. The genital plates are fused with the central pentagonal plate and the gonopores are present at the angles of the pentagon.

Diadema (Centrechinus)

Diadema (Fig. 18.24F) is a typical genus under the family Diadematidae. It lives in littoral and sublittoral zones of the tropical and subtropical regions. The common Indo-Pacific species of the genus are *Diadema setosum* and *Diadema savignyi*. Diadema is very large in size with long primary spines. These spines may reach a length of 30 cm. The spines are very sharply pointed. The test is inflexible and the aboral interambulacral areas lack spines. The periproct is devoid of skeletal elements and possesses a prominent anal cone. The globiferous pedicellariae are absent.

Arbacia

Arbacia (Fig. 18.24C) belongs to the family Arbaciidae. They usually live in the littoral zones. The peculiarities of the genus are the presence of the primary spines and the possession of one sphaeridium in each ambulacrum at the oral end. The sphaeridia are placed in pit-like cavities distributed along the centre of the ambulacra. The periproct contains usually four or five plates which act as valves for the centrally placed anus. The primary spines are of moderate size and the secondary spines are absent.

Laganum

Laganum (Fig. 18.25A) belongs to the family Laganidae. They inhabit the sandy bottoms in shallow water of Indo-West Pacific region. The test is small, flattened and circular in outline. The ambulacra at the aboral side become petaloid. The apical skeletal elements are fused into a central pentagonal plate containing five gonopores. The madreporic pores usually sink into pits. The oral surface bears five

ambulacral grooves not reaching the edge of the test. The periproct is situated on the oral surface.

Echinocardium

Echinocardium (Fig. 18.25E) is the typical Heart Urchin under the family Loveniidae. The members under the genus enjoy cosmopolitan distribution. They bury in sand. The test is large in size with four well-developed petaloids. On the aboral side, the large spine tubercules with deeply sunken areoles, so common in other genera, are wanting. The apical central plate contains four gonopores. The peristome becomes transversely extended. The lantern of Aristotle is absent. The ambulacra bear numerous short tube-feet and short spines. The interambulacra bear long spines.

Thyone

Thyone (Fig. 18.25D) is a typical genus under the family Cucumaridae. It is found to remain buried in sandy and muddy bottoms. The body is more or less oval with ten branched tubules. The mid-ventral pair of the tentacles is smaller than the others. The tube-feet are present all over the body without having any specific orientation in the ambulacral areas. The respiratory trees are present, but the Cuverian tubules are absent. The haemal system is very simple. The haemocytes in the coelomic fluid contain haemoglobin. The stomach is an elongated muscular sac of limited length and not very extensive as in other holothurians.

Cucumaria

Cucumaria belongs to the family Cucumaridae (see Fig. 8.12E). At the oral end there are ten tentacles. The tube-feet are distributed as five distinct ambulacral bands. In the interambulacral areas tube-feet are a few in number and are haphazardly distributed. In *Cucumaria frondosa*, numerous (about 50) male gonopores are present. The haemocytes in the coelomic fluid also contain haemoglobin. The complicated lacunar networks connecting the intestine is absent. They are hermaphroditic.

Pelagothuria

Pelagothuria (Fig. 18.25B) is a typical elasipod genus. It is a floating form, ranging from the surface to considerable depths. It has an oval body without ossicles. The mouth is wide and terminal. It is surrounded by a circlet of tentacles with bifurcated tips. The number of tentacles varies from 13–20 in different species. A floating sail supported by many long papillae is present just behind the circlet of tentacles. This sail may be restricted to the dorsal side or may encircle the body. The tube-feet are ill-developed. The stone canal opens to the exterior near the genital papillae.

Opheodesoma

Opheodesoma (see Fig. 8.12B) belongs to the family Synaptidae. It lives completely in buried condition in muddy and sandy bottoms of the sea. It has an elongated vermiform body which may reach the length of about two to three feet. About fifteen well-developed pinnate tentacles are present. The tube-feet are absent. The respiratory trees are absent and the thin body wall serves as the respiratory surface. The body wall contains anchor plates. The sigmoid ossicles are lacking.

Ophioderma

Ophioderma is a well-known representative of the family Ophiodematidae. The body consists of a small pentagonal disc covered by closely set granules. The oral papillae are numerous and are arranged in a continuous series. The teeth are present in a single row and the dental papillae are absent. The spines of the arms are small. The most important individual characteristic feature of the genus is the presence of two slits in each bursa, one situated orally and the other peripherally.

Gorgonocephalus (Basket-star)

Gorgonocephalus is the best known genus of the family Gorgonocephalidae. The body consists of a large disc and many elongated extensively branched flexible tentacles (Fig. 18.25F). Gorgonocephalus starts life with five arms which become repeatedly branched in advanced stage. The oral surface of the arms is spiny and the aboral surface is annulated due to lack of true aboral arm shields. The lateral and oral arm shields are present. The margin of the disc between the radial shields is provided with series of plates. The oral papillae and tooth papillae are present. The gonads are restricted to the

interior of the disc. The bursae become fused to form large cavities which suppress the coelom.

Metacrinus

Metacrinus is a very common pentacrinite genus of the family Isocrinidae. This genus

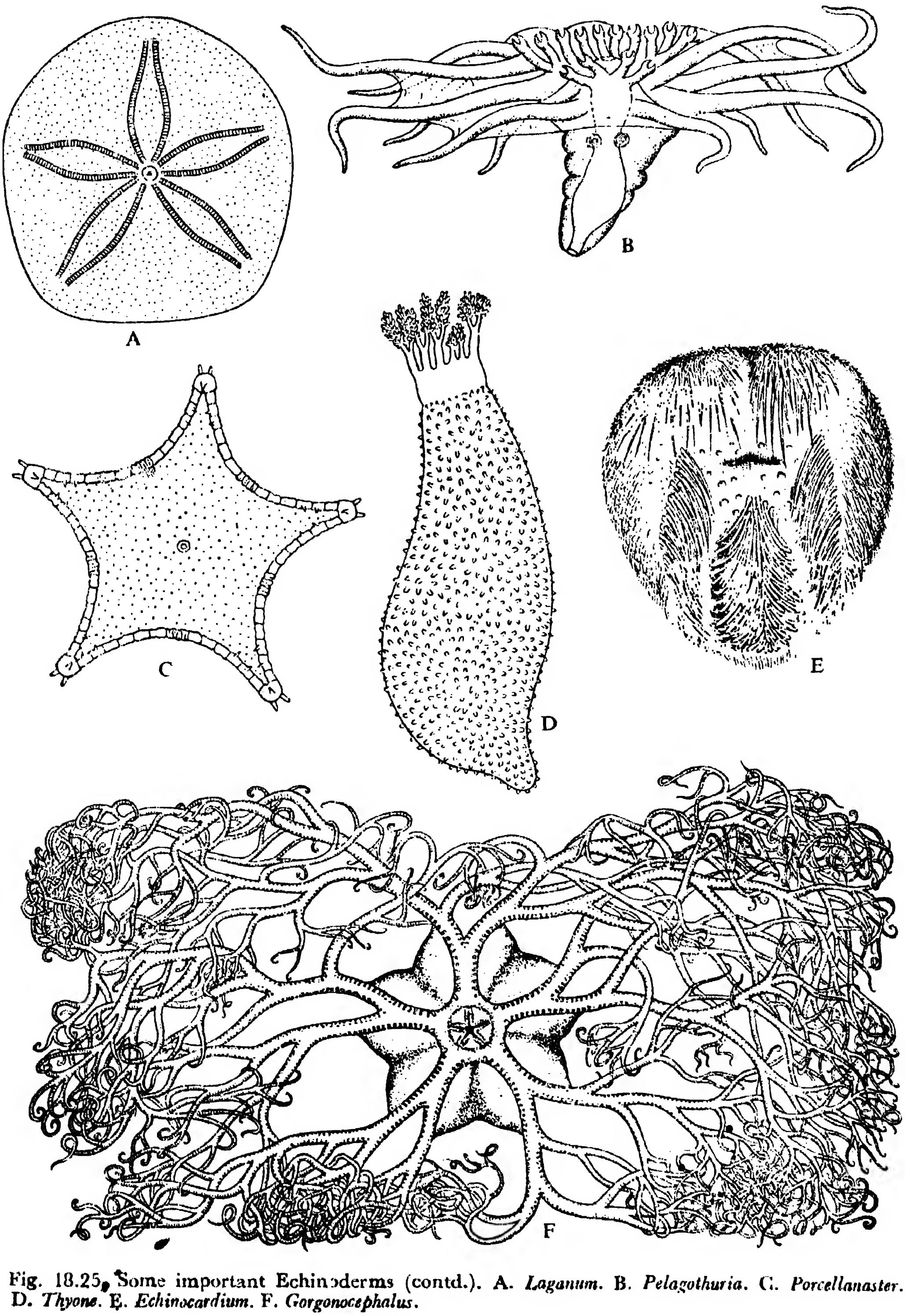


Fig. 18.25. Some important Echinoderms (contd.). A. *Laganum*. B. *Pelagothuria*. C. *Porcellanaster*. D. *Thyone*. E. *Echinocardium*. F. *Gorgonocephalus*.

is distributed in the Japan-Malay-Australian region. The stalk is long, pentagonal and with many joints or nodes. Encircling the nodes, there are whorls of five many-jointed cirri for temporary attachment. The arms are much branched, pinnulated and arranged like a crown of flower. The most important characteristic of the genus is the existence of four brachial ossicles between the radials and the first branching. All the forks of the arms are separated by a number of brachials.

CLASSIFICATION

CLASSIFICATION IN OUTLINE

The phylum Echinodermata includes a large variety of extinct as well as living forms. They are non-colonial marine coelomates. This phylum is divided into two Subphyla—Eleutherozoa and Pelmatozoa. The scheme of classification presented here is largely based on the classificatory plan outlined by L. H. Hyman. Recently H. B. Fell (as per the book entitled, Text Book of Zoology—Parker & Haswell—Vol. I, 7th edition) has altogether presented a quite different scheme. An outline classificatory scheme of Phylum Echinodermata into different subgroups is given separately.

Subphylum ELEUTHEROZOA
- Class **Asteroidea**
  - Order *Platyasterida*, e.g. *Platanaster*.
  - Order *Hemizonida*, e.g. *Anthraster*, *Taeniactis*.
  - Order *Phanerozonia*
    - *Suborder* Pustulosa, e.g. *Hudsonaster*.
    - *Suborder* Cribellosa, e.g. *Porcellanaster*.
    - *Suborder* Paxillosa, e.g. *Ctenodiscus*.
    - *Suborder* Notomyota, e.g. *Nearchaster*.
    - *Suborder* Valvata, e.g. *Archaster*.
  - Order *Spinulosa*, e.g. *Asteria*, *Echinaster*.
  - Order *Forcipulata*, e.g. *Asterias*, *Odinia*.
- Class **Echinoidea**
  - *Subclass* BOTHRIOCIDAROIDA, e.g. *Bothrioidaris*.
  - *Subclass* REGULARIA or ENDOCYCLICA
    - Order *Lepidocentroida*, e.g. *Phormosoma*, *Palaeodiscus*.
    - Order *Melonechinoida*, e.g. *Melonechinus*.
    - Order *Cidaroidea*, e.g. *Eucidaris*.
    - Order *Aulodonta*, e.g. *Plesiodiadema*, *Aspidodiadema*.
    - Order *Stirodonta*, e.g. *Salenocidaris*, *Arbacia*.
    - Order *Camarodonta*, e.g. *Echinus*, *Mespilia*.
  - *Subclass* IRREGULARIA or EXOCYCLICA
    - Order *Holectypoida*, e.g. *Pygaster*, *Plesiechinus*.
    - Order *Cassiduloida*, e.g. *Apatopygus*, *Cassidulus*.
    - Order *Clypeastroida*, e.g. *Clypeaster*, *Echinocyamus*.
    - Order *Spatangoida*, e.g. *Urechinus*, *Aeropsis*.
- Class **Holothuroidea**
  - Order *Aspidochirota*, e.g. *Holothuria*, *Actinopyga*.
  - Order *Dendrochirota*, e.g. *Cucumaria*, *Thyone*.
  - Order *Elasipoda*, e.g. *Deima*, *Elpidia*.
  - Order *Molpadonia*, e.g. *Caudina*, *Molpadia*.
  - Order *Apoda* or *Synaptida*, e.g. *Synapta*, *Rhabdomolgus*.
- Class **Ophiuroidea**
  - Order *Ophiurae*, e.g. *Ophiura*, *Ophiomyxa*.
  - Order *Euryalae*, e.g. *Euryale*, *Asteronyx*.
- Class **Ophiocistioidea,** e.g. *Sollasina*.

Subphylum PELMATOZOA
- Class **Heterostelea,** e.g. *Placocystis*, *Trochoystites*.
- Class **Cystidea**
  - Order *Rhombifera*, e.g. *Caryocrinites*, *Echinosphaerites*.
  - Order *Diploporita*, e.g. *Proteroblastus*, *Mesocystis*.
- Class **Blastoidea,** e.g. *Pentremites*, *Codaster*.
- Class **Crinoidea**
  - Order *Articulata*, e.g. *Antedon*, *Metacrinus*.
  - Order *Inadunata*, e.g. *Anartiocrinus*, *Hybocystites*.
  - Order *Flexibilia*, e.g. *Forbesiocrinus*.
  - Order *Camerata*, e.g. *Reteocrinus*, *Xenocrinus*.
- Class **Edriaasteroidea,** e.g. *Stromatocystites*, *Cystaster*.

CLASSIFICATION WITH CHARACTERS

Subphylum Eleutherozoa

The stalkless adult moves freely. The ambulacral grooves radiate from the mouth and possess double series of tube-feet or podia. The tube-feet are usually provided with terminal suckers and are locomotory in function. The mouth is situated on the oral surface of the body which is normally directed downwards. The anus, when present, is placed aborally.

Class **Asteroidea**

The body is star-shaped or pentagonal with a flattened central disc. The arms are hollow and each arm bears continuation of the coelom. The number of the arms are usually five which may increase in some forms. The ambulacral grooves are open and contain rows of tube-feet. The ambulacra are restricted to the oral surface of the body. The oral and aboral surfaces are quite distinct. The skeleton is flexible. The madreporite is situated on the aboral surface. The pedicellariae are present. The gonads are radially placed. The larval forms are bipinnaria and/or brachiolaria.

Order *Platyasterida*

The order includes fossil starfishes. The typical example is *Platanaster*. The fossils were abundant from Ordovician to Devonian periods. The aboral surface bears large upright spines beset with two or three circlets of small spinelets. The margin of the arm is formed by the inframarginal plates.

Order *Hemizonida*

This order also includes fossil asteroids ranging from Ordovician to middle Carboniferous periods. Distinct ambulacral grooves are present. The madreporite is present either orally or aborally. Examples —*Taeniactis*, *Anthraster*, *Helianthaster*, *Lepidactis*, *Cnemidactis*.

Order *Phanerozonia*

The body is a large disc with usual five arms. Around the margin of the disc and the arms, large marginal plates (infra- and supramarginal plates) are present. The dermal papulae are restricted to the aboral surface. The tube-feet are arranged in double rows along the ambulacral grooves. The tube-feet may lack suckers. The pedicellariae, when present, are sessile. This order is subdivided into the following suborders:

Suborder Pustulosa

The members are all extinct. The fossils were distributed from lower Ordovician to Permian periods. The spines are smaller and slender. They are placed on hemispherical tubercles. The peristome is bordered by ambulacral and adambulacral ossicles. Example—*Hudsonater*.

Suborder Cribellosa

The members are mud-dwellers. The body is stellate-shaped and the arms are slender and pointed. The tube-feet lack terminal suckers. The digestive system lacks intestine and anus. The ampullae are simple. Examples—*Porcellanaster*, *Eremicaster*, *Styracaster*, *Hyphalaster*, *Thoracaster*.

Suborder Paxillosa

Typical paxillae constitute the aboral skeleton of the body. The tube-feet lack suckers. The ampullae are bifurcated. Examples—*Ctenodiscus*, *Goniopecten*, *Astropecten* (Fig. 18.23), *Dipsacaster*, *Luidia*.

Suborder Notomyota

The tube-feet are provided with suckers. A pair of strongly built dorso-lateral muscle bands is present in each arm. The aboral plates are greatly reduced. The spines are smaller. Examples—*Nearchaster*, *Pontaster*, *Pectinaster*, *Benthopecten*.

Suborder Valvata

The tube-feet bear terminal suckers. The aboral plates are usually flattened and have mosaic arrangement. Examples—*Archaster*, *Odontaster*, *Acodontaster*, *Notioceramus*, *Chitonaster*.

Order *Spinulosa*

The marginal plates of the arms are either wanting or inconspicuous. The spines are present on the aboral surface, either singly or in groups. The pedicellariae are rarely present. The tube-feet are provided with suckers and occur in two rows in each ambulacral groove. The

ampullae may be simple or bifurcated. Examples—*Asterina*, *Echinaster*, *Henricia*, *Ganeria*, *Cycethra*, *Patiria*, *Solaster* (Fig. 18.24E).

Order *Forcipularia*

The marginal plates are not prominent. The spines occur singly. The papulae are present on both the oral and aboral surfaces of the body. The pedicellariae are stalked. The tube-feet are arranged in two or four rows and are provided with suckers. Examples—*Asterias*, *Odinia*, *Ordinella*, *Asterostephane*, *Heliaster* (Fig. 18.24A), *Zoroaster* (Fig. 18.24D).

Class **Echinoidea**

The body may be globular, heart-shaped, oval or disc-like. The body is enclosed by a skeleton in the form of a continuous test of closely set calcareous plates. The spines are movable. The ambulacral grooves are absent as such, but the surface is divided into alternate ambulacral and interambulacral areas. The ambulacral areas extend from the oral to the aboral pole of the body. The ambulacral plates have pores for the passage of the tube-feet. The tube-feet are highly extensible, provided with suckers and are locomotory in function. The mouth and anus are surrounded by membranous peristome and periproct respectively. The gonads are pentamerous. The larva is Echinopluteus.

Subclass Bothriocidaroida

This subclass contains fossil echinoids represented by a single genus, *Bothriocidaris*. The test is rigid and round in shape. Each ambulacrum has two rows of plates and the interambulacrum has single row of plates. The typical lantern of Aristotle is absent. The madreporite is radially disposed.

Subclass Regularia or Endocyclica

The test is globular and exhibits distinct pentamerous symmetry. Each interambulacrum has two rows of plates. The lantern of Aristotle is well developed. This subclass includes six orders.

Order *Lepidocentroida*

The order includes both fossil and living echinoids with flexible test. The fossil forms had 2–40 rows of plates in the interambulacra. The periproct is supported by apical plates. Examples—*Aulechinus*, *Myriastiches*, *Palaeodiscus*, *Tromikosoma*, *Asthenosoma*.

Order *Melonechinoida*

The members are all extinct. The test is rigid. There are 4–11 rows of interambulacral plates. The gills are absent. The ambulacra continue up to the mouth. Example—*Melonechinus*.

Order *Cidaroida*

The order includes both extinct and existing echinoids. The test is round. There are two rows of plates in the interambulacra. Each interambulacral plate bears one large spine which is surrounded by small spines at the basal end. The gills and the sphaeridia are absent. Examples—*Cidaris*, *Phyllacanthus*, *Stylocidaris*, *Prionocidaris*, *Goniocidaris*.

Order *Aulodonta*

This order contains both fossil and living echinoids. The test is globular. The plates in the ambulacra are compound. The gills and sphaeridia are present. The epiphyses of the lantern are small and do not meet the pyramids above. The teeth are devoid of keel. Examples—*Plesiodiadema*, *Caenopedina*, *Micropyga*, *Diadema* (Fig. 18.24F), *Astropyga*, *Centrostephanus*.

Order *Stirodonta*

This order is almost similar to Aulodonta, but the teeth are with keel. The test is rigid. The spines are solid. Examples—*Salenocidaris*, *Salenia*, *Arbacia* (Fig. 18.24C), *Coelopleurus*.

Order *Camarodonta*

The test is oval. The epiphyses of the lantern are greatly enlarged and meet the pyramids to form bar. The teeth are provided with keel. The spines are solid, but lack cortex. Examples—*Salmacis*, *Microcyphus*, *Nudechinus*, *Echinus*, *Toxopneustes*, *Parasalenia*, *Echinometra*.

Subclass Irregularia or Exocyclica

The test is mostly flattened and the shape is either oval or round. The ambulacra have become converted into petaloid condition at the aboral side. The tube-feet are mostly non-locomotory.

Order *Holectypoida*

This order includes extinct forms. The test is regular. The ambulacra are simple and do not show petaloid development. The lantern of Aristotle is present. Examples: *Pygaster*, *Plesiechinus*, *Holectypus*, *Echinoneus*, *Micropetalon*.

Order *Cassiduloida*

This order includes mostly the fossil forms. The test is round or oval in outline. In the living forms the lantern of Aristotle is absent in adult. The ambulacra become petaloid at the aboral end. The genital plates are usually fused with the madreporite. Examples: *Apatopygus*, *Cassidulus*, *Tropholampas*, *Anochanus*.

Order *Clypeastroida*

The members of this order are called sand dollars. They have irregular body with flattened test. The lantern is present. The gills are lacking. The mouth is centrally placed but the anus is excentric. The ambulacra at the aboral side are petaloid. Examples: *Clypeaster* (Fig. 18.24G), *Arachnoides*, *Echinocyamus*, *Fibularia*, *Laganum* (Fig. 18.25A).

Order *Spatangoida*

The members of this order are called heart urchins. The body is irregular with an oval test. The lantern and the gills are absent. The mouth and anus are excentrically placed. Four of the five ambulacral areas have become petaloid at their aboral ends. Examples: *Plexechinus*, *Urechinus*, *Pilematechinus*, *Pourtalesia*, *Palaeostoma*, *Aeropsis*, *Echinocardium* (Fig. 18.25E).

Class **Holothuroidea**

The body is cylindrical and exhibits bilateral symmetry. The oral-aboral axis is elongated. The mouth and anus are located at the opposite extremities of the body. The skin is soft, thin and without spines and pedicellariae. The endoskeleton is reduced to microscopic calcareous spicules and ossicles in the body wall. A circlet of long oral tentacles is present at the oral end. The surface of the body may exhibit five ambulacral areas. The stone canal lacks the external opening. The tube-feet are locomotory in function and are usually restricted to the five ambulacral areas. The larva is auricularia.

Order *Aspidochirota*

The tube-feet are numerous. The oral tentacles are shield-shaped and the number is 20 in most cases. The pharyngeal retractor muscles are absent. The tentacular ampullae are present. The respiratory trees are well-formed. Examples: *Holothuria*, *Actinopyga*, *Stichopus*, *Pseudostichopus*, *Bathyplotes*, *Synallactes*.

Order *Elasipoda*

The tube-feet are numerous. The oral tentacles are shield-shaped and their number varies from 10–20. The tentacular ampullae are absent. The pharyngeal retractor muscles are absent. The respiratory trees are lacking. Examples: *Deima*, *Oneirophanta*, *Laetmogone*, *Benthodytes*, *Peniagone*, *Scotoanassa*, *Pelagothuria* (Fig. 18.25B).

Order *Dendrochirota*

The tentacles are arborescent. The tentacular ampullae are absent. The tube-feet are present. They may spread all over the body or may be restricted to the ambulacral areas. The pharyngeal retractor muscles and the respiratory trees are present. The respiratory trees lack Cuvierian tubules. Examples: *Cucumaria*, *Thyone*, *Pentacta*, *Sphaerothuria*, *Echinocucumis*, *Psolus*, *Phyllophorus*.

Order *Molpadonia*

The tube-feet are absent. The tentacles are small, unbranched and the number varies from 10–15. The tentacular ampullae are present. The respiratory trees are present Examples: *Gephyrothuria*, *Molpadia*, *Caudina*, *Paracaudina*, *Acaudina*.

Order *Apoda* or *Synaptida*

The body is elongated and vermiform. The tube-feet are absent. The water vascular system is greatly reduced and the radial ambulacral vessels are absent. The tentacles are pinnately branched and the number vary from 10–20. The tentacular ampullae are vestigial or absent. The respiratory trees are absent. Examples: *Synapta*, *Synaptula*, *Opheodesoma* (see Fig. 8.12B), *Leptosynapta*, *Protankyra*.

Class **Ophiuroidea**

The body is pentamerous and star-shaped. It has a distinct central disc with five elongated flexible arms. The arms are

sharply marked off from the central disc. The ambulacral grooves are absent excepting some fossils. The body is flattened with distinct oral and aboral surfaces. There are no spacious prolongations of the coelom into the arms. The anus is lacking. The mouth and madreporite are situated on the oral surface of the body. The gonads are pentamerous and the genital bursae usually act as the gonoducts. The larva is Ophiopluteus.

Order *Ophiurae*

This order includes the serpent stars or brittle stars. The arms are simple, unbranched and five in number. The arms can move along the transverse plane of the body. The arms can not twine around any object. The madreporite is single. The spines are directed outward. Examples: *Ophiomyxa*, *Sigsbeia*, *Ophioplus*, *Amphiura*, *Ophiura*, *Ophiothrix*, *Ophioderma*.

Order *Euryalae*

The arms are usually branched and can move vertically. They can coil themselves around any object. The spines are directed downward. The spines are often modified into hooks. There exists one madreporite at each inter-radius and the number corresponds with that of the stone canal. Examples: *Asteronyx*, *Conocladus*, *Gorgonocephalus* (Fig. 18.25F), *Astrophyton*, *Astrogymnotes*, *Euryale*.

Class **Ophiocistioidea**

This class includes peculiar fossil echinoderms. The fossils were abundant from Ordovician to Devonian periods.

The body is disc-like and is without arms. The body is enclosed by a theca. The theca is composed of plates excepting the peristome and is distinctly pentamerous on the oral side where the five ambulacral areas alternate with five interambulacral areas. Each ambulacrum has three rows of plates and an interambulacrum possesses one row of plates. There are two to eight pairs of giant tube-feet on the oral side of each ambulacrum. The tube-feet are covered by small plates. Examples: *Eothuria*, *Sollasina*, *Eucladia*, *Bothriocidaris*, *Volchovia*.

Subphylum PELMATOZOA

The subphylum Pelmatozoa is characterised by the possession of certain peculiar features. This subphylum contains a large number of fossil echinoderms. The members usually remain fixed throughout life or only in the young stage by aboral side or by a stalk. The stalk is supported by rows of calcareous ossicles. The free end or the oral surface of the disc bears the mouth at the centre. The anus is also situated on this surface. The viscera are enclosed in a calcareous theca. The ciliated ambulacral grooves function as the food-grooves. The tube-feet, when present, are small tubular ciliated tentacles without suckers. They help primarily in food catching.

Class **Heterostelea**

This class also contains fossil forms with laterally flattened non-porous theca. The radial symmetry is absent. The fossils were present from Cambrian to lower Silurian. The body is fixed by stalk which is composed of two or more rows of skeleton. Examples: *Placocystis*, *Cothurnocystis*, *Trochocystites*, *Dendrocystites*.

Class **Cystidea**

The representatives of the class constitute a very well-known group of extinct echinoderms distributed from the Ordovician to Silurian periods. They have vase-like bodies which remain fixed with the substratum directly or through a stalk. The theca is composed of many rigid polygonal plates. The plates constituting the theca are mostly porous and are perforated by canals. The food-grooves extend over the surface of the theca. The branchioles are devoid of pinnules.

Order *Rhombifera*

The thecal canals produce various types of pores in a few or in all plates of the theca. Examples: *Caryocystites*, *Echinosphaerites*. *Glyptocystites*, *Lovenicystis*, *Cystoblastus*.

Order *Diploporita*

The thecal canals are usually in the form of diplopores in all or in some of the thecal plates. Examples: *Proteroblastus*, *Aristocystites*, *Sphaeronites*, *Mesocystis*, *Asteroblastus*.

Class **Blastoidea**

The members of this extinct class had pentamerous radially symmetrical thecae consisting of thirteen plates in three rows.

The fossils were abundant from Ordovician to Permian periods. They were mostly fixed forms and remained attached with the substratum directly or through a short stalk. The ambulacra are petaloid and are five in number. They possess the characteristic respiratory structures called hydrospires. Examples: *Codaster, Pentremites, Phaenoschisma, Orophocrinus, Troostocrinus, Zygocrinus.*

Class **Crinoidea**

This class includes both living and extinct representatives. The existing members are mostly free-living and stalkless. The body exhibits strong pentamerous symmetry. The oral surface is directed upwards and the theca on the aboral side is differentiated into a non-porous cup-like calyx. The arms are movable, branched and may be devoid of pinnules. The mouth is centrally placed and the anus is generally excentrically placed on the oral surface of the body. The food-grooves radiate from the mouth to the oral surface of the arms and extend to the tip of the pinnules.

Order *Articulata*

This order contains both living and fossil crinoids with flexible pentamerous calyx. The arm ossicles on the lower side are united with the calyx. The arms are generally branched. The tegmen is leathery with small plates. The ambulacra and the mouth remain open. Examples: *Millericrinus, Pharynocrinus, Bourgueticrinus, Rhizocrinus, Isocrinus, Antedon.*

Order *Inadunata*

This order includes extinct crinoids ranging from Silurian to Permian periods. The calyx is rigid and the ambulacra are mostly open. The pinnules may or may not be present. The lower arm ossicles are separated from the calyx. Examples: *Hybocystites, Anartiocrinus, Ottawacrinus.*

Order *Flexibilia*

This order also includes fossil crinoids distributed from Ordovician to Permian periods. The calyx is flexible and the ambulacra are covered. The pinnules are totally absent. The lower arm ossicles are united with the calyx. Example: *Forbesiocrinus.*

Order *Camerata*

Members of this extinct order of crinoids were abundant from Ordovicin to Permian periods. The calyx is rigid with branched pinnulated arms. The arm ossicles on the lower side are united with calyx. The tegmen is armoured with plates and covers the mouth and ambulacra. Usually an anal tube is present. Examples: *Xenocrinus, Reteocrinus, Archaeocrinus, Platycrinus, Technocrinus.*

Class **Edrioasteroidea**

Extinct forms are with disc-like body and remain fastened by the aboral end. They are fixed forms but without stalk. The theca is sac-like, flexible and composed of numerous polygonal plates. Five curved or straight ambulacra radiate from the central mouth. The ambulacra bear pores for the passage of the tube-feet. Fossils extend from Cambrian to lower Carboniferous. A hydropore between the mouth and anus is reported to be present. Examples: *Stromatocystites, Walcottidiscus, Carneyella, Cystaster, Cooperidiscus, Isorophus.*

An outline scheme of classification of the phylum Echinodermata according to H. B. Fell is given in page 612.

GENERAL NOTES ON ECHINODERMS

HISTORY

The member of the phylum Echinodermata are known to mankind from ancient times. Echinoderms were first given the status of a distinct group by Bruguiere in 1791. But the credit of coining the term Echinodermata goes to Klein (1734). Linnaeus studied a number of Echinoderms, but placed *Echinus, Asterias* and *Holothuria* under Mollusca. Lamarck (1801) included the Echinoderms and medusoid Coelenterates under the class Radiata. Leuckart (1854) opposed the concept of Radiata and separated the Echinoderms from Coelenterates. Echinoderms were placed in a distinct phylum Echinodermata and were considered as a group higher in evolutionary scale than Coelenterata.

Phylum—Echinodermata
(Subphylum)

- I. Echinozoa
- II. Homalozoa (Class)
  - Carpoidea: e.g. *Enoploura*
- III. Crinozoa
- IV. Asterozoa

Subphylum: I—Echinozoa
(Class)

- Helicoplacoidea, e.g. *Helicoplacus*
- Holothuroidea (Subclass)
  - Dendrochirotacea (Orders)
    - *Dactylochirotida*, e.g. *Ypsidothuria*
    - *Dendrochirotida*, e.g. *Placothuria*
  - Aspidochirotacea (Orders)
    - *Aspidochirotida*, e.g. *Stichopus*
    - *Elasipodida* e.g. *Elpidia*
  - Apodacea (Orders)
    - *Molpadida*, e.g. *Molpadia*
    - *Apodida*, e.g. *Leptosynapta*
- Edrioasteroidea, e.g. *Edrioaster*
- Echinoidea (Subclass)
  - Perischoechinoidea (Orders)
    - *Echinocystitoida*, e.g. *Eothuria*
    - *Bothriocidaroida*, e.g. *Bothriocidaris*
    - *Palaechinoidea*, e.g. *Palaechinus*
    - *Cidaroida*, e.g. *Goniocidaris*
  - Euechinoidea (Super orders)
    - Diadematacea (Orders)
      - *Echinothurioida*, e.g. *Araeosoma*
      - *Diadematoida*, e.g. *Diadema*
      - *Pedinoida* e.g. *Pedinus*
      - *Pygasteroida*, e.g. *Pygaster*
    - Echinacea (Orders)
      - *Hemicidaroida* e.g. *Hemicidaris*
      - *Salenioida*, e.g. *Salenocidaris*
      - *Phymosomatoida*
      - *Arbacioida*, e.g. *Arbacia*
      - *Temnopleuroida* e.g. *Mespilia*
      - *Echinoida*, e.g. *Echinus*
    - Gnathostomata (Orders)
      - *Holectypoida*, e.g. *Holectypus*
      - *Clypeasteroidea*, e.g. *Laganum*
    - Atelostomata (Orders)
      - *Cassiduloida*, e.g. *Apatopygus*
      - *Holasteroida*, e.g. *Echinosigra*
      - *Spatangoida*, e.g. *Echinocardium*
- Ophiocistioidea, e.g. *Volchovia*

Subphylum: III—Crinozoa (This subphylum includes six classes of which the Class Crinoidea has representatives in existing seas).

↓

Class : Crinoidea

↓

(Subclass)

↓

- Inadunata, e.g. *Dendrocrinus*
- Camerata, e.g. *Xenocrinus*
- Flexibilia, e.g. *Endriocrinus*
- Articulata, e.g. *Metacrinus*

Subphylum: IV—Asterozoa (Possesses only one class: Stelleroidea)

Class: Stelleroidea

↓

(Subclass)

↓

- Somasteroidea, e.g. *Ampullaster*
- Asteroidea
  ↓
  (Orders)
  - →*Platyasterida*, e.g. *Luidia*
  - →*Phanerozonida*, e.g. *Pentagonaster*
  - →*Spinulosida*, e.g. *Solaster*
  - →*Euclasteroida*, e.g. *Brisingenes*
  - →*Forcipulatida*, e.g. *Astrostole*
- Ophiuroidea
  ↓
  (Orders)
  - →*Stenurida*, e.g. *Stenurus*
  - →*Oegophiurida*, e.g. *Ophiocanops*
  - →*Phrynophiurida*, e.g. *Astrophyton*
  - →*Ophiurida*, e.g. *Ophiomisidium*

Huxley (1875) proposed a new name *Deuterostomata* and placed all the bilaterally symmetrical coelomates under the group. The term *Enterocoela* including Chaetognatha, Echinodermata, Hemichordata and Chordata, was also used by many authors. The group Enterocoela seems to be synonymous with Deuterostomata. It is now established that the different groups under Deuterostomata or Enterocoela are widely separated for their structural diversities and there is no justification to include them under one group. Metschnikoff (1881) included the Echinoderms and Hemichordates under *Ambulacraria* on the basis of striking resemblances between the Echinoderm larvae and Tornaria larva of Hemichordata. In spite of the similarities between Echinoderms and Hemichordates, they are placed in separate groups. The names of Bather (1900), Mortensen and Lieberkind (1928), Cuenot (1948) are to be mentioned for their outstanding and extensive treatise on different Echinoderms.

HABIT AND HABITAT

Echinoderms are exclusively marine animals. They inhabit all the seas and in all latitudes. They are usually absent in colder areas, excepting Crinoids which are not uncommon in arctic and antarctic regions. Echinoderms are found from the intertidal zone to the depth of about 6,000 m. Almost all the Echinoderms are benthonic and live in all types of sea bottoms. Asteroids crawl on the bottom and a few forms, belonging to the family *Benthopectinidae*, swim by the arms. The Holothurians remain adhered to the rocky bottoms and conceal themselves under rocks. Some Holothurians like *Holothuria*, *Stichopus*, *Actinopyga*, are adapted to the sandy bottom. Some of them remain partly or wholly buried in sandy or muddy bottoms. *Leptosynapta* spends entire life being completely buried in soft bottoms and they move under the surface. Echinoids are also benthonic animals and keep the oral surface of the body in contact with the substratum. Some Echinoids are rock-borers and make bores like honey-combs in the rocky wall. The typical rock-boring Echinoids are *Psammechinus miliaris* and *Paracentrotus livides*. The Ophiuroids inhabit all sorts of sea-beds. They usually hide under rocks and sea-weeds. They remain attached to other objects by their flexible arms. They exhibit various types of movement by the arms. Some Ophiuroids have the habit of burrowing in sand as seen in *Amphiura chiajei*. The crinoids are shallow-water inhabitants, except the stalked forms which occur mostly in deep sea ranging from 200–5000 m.

Most of the Echinoderms are sluggish animals and move very slowly. They can either crawl on the surface or may swim in water by the arms. The ophiuroids are the most active forms amongst the Echinoderms. The Crinoids are more or less sedentaric animals. Most of the adult Crinoids are stalked and remain fastened to the bottom by aboral side of the body directly or through a stalk. The deep sea forms are generally stalked. A few Crinoids detach themselves from the stalk in adults and usually lead free and pelagic life.

Echinoderms are gregarious animals and usually live in large groups. They are mostly nocturnal. They are bottom feeders and eat all sorts of food available in the sea bottoms. Most of them are carnivorous but several herbivorous forms are also known.

SIZE

The sizes of Echinoderms are relatively moderate. The largest Asteroid known is *Pycnopodia helianthoides* which measures about 90 cm. The largest urchin living in the deep sea realms is *Echinosoma hoplacantha* whose shell is about 31 cm across. In another urchin, *Diadema*, the spines are about 30 cm long. *Synapta muculata*, a Holothurian, has 16 cm long body with the diameter of about 6 cm. The stem of some fossilised Crinoids is about 2 m in length. As regards the smallest representatives of the group, it is seen that some fossil sand dollars measure only 2·5 cm.

SHAPE AND SYMMETRY

The phylum Echinodermata constitutes a very well-defined group. They exhibit distinct radial symmetry in adults, excepting some Holothurians where the radial symmetry is not marked externally. The disposition of both internal and external structures also exhibits radial symmetry in Echinoderms which is an exception among the Coelomata. The radial symmetry in adult organisation is acquired at the time of metamorphosis because the larval stages of all Echinoderms have bilaterally symmetrical bodies. All the Echinoderms have a

pentamerous body plan and have distinct oral and aboral surfaces. The terms 'dorsal' and 'ventral' are not applied in Echinoderm organisation. The mouth is centrally situated at the oral surface excepting a few Echinoids, Holothurians and *Actinometra* (Crinoid) where the position of the mouth is slightly shifted from its original place. But the position of anus varies quite greatly (Fig. 18.26) and it is located excentrically. In some Echinoids and Crinoids, the anus is placed on the oral surface. The anus may be totally wanting in a few adult Asteroids and Ophiuroids.

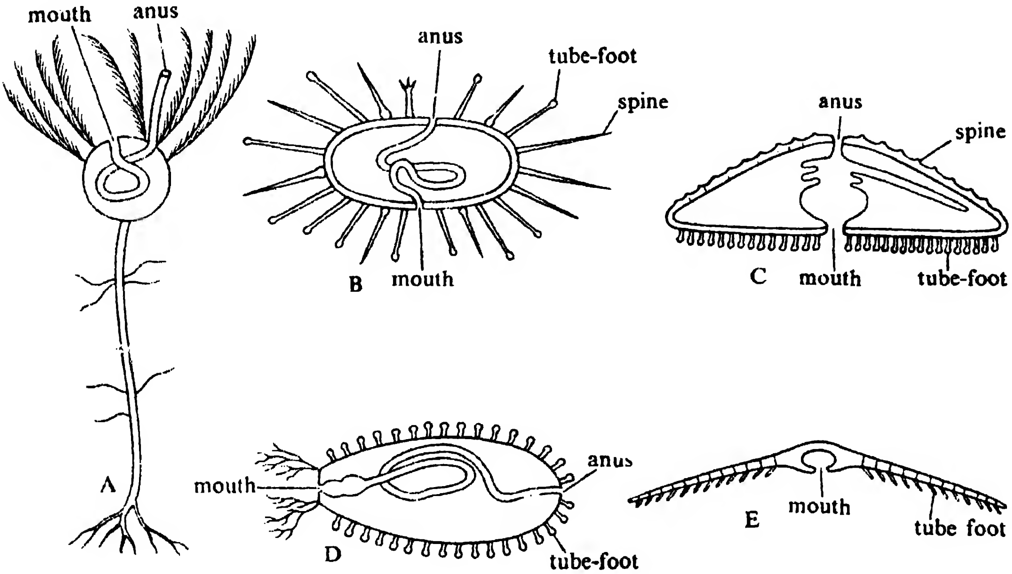


Fig. 18.26. Figures showing the relative position of mouth and anus in different Echinoderms. A. *Antedon*. B. *Echinus*. C. *Asterias*. D. *Holothuria*. E. *Ophiura*. Note that the anus is absent in *Ophiura*.

The symmetry of the body has moulded all the organs of the body. Externally, the radial symmetry is exhibited by *radii* and *inter-radii*. The radii are marked by rows of tube-feet and the inter-radii are the portions of the body between the radii. But in some Holothurians, the tube-feet may spread over the inter-radii of the body. The tube-feet are usually restricted to the oral surface (excepting Holothurians and Echinoids where the tube-feet extend up to the aboral side to some extent) which is also called *actinal* or *ambulacral* surface. The other side (without tube-feet) is called *abactinal* or *adambulacral* surface. The body is prolonged into arms in the direction of the radii in Asteroidea, Ophiuroida and Crinoida but in roundish Echinoids and sausage-shaped Holothurians, the aboral surfaces are inconspicuous due to the extension of the ambulacral surfaces.

In all the members of the subphylum Eleutherozoa, excepting the Holothurians, the mouth is directed downwards. In Holothurians, the mouth is horizontally directed and they apply one side of the body to the ground. But in Crinoids, the mouth is directed upwards.

Presence of *tube-feet* or *podia* is the characteristic feature of the phylum. In Asteroidea, Echinoidea and Holothuroidea, the tube-feet are provided with terminal suckers and they help in locomotion. In other forms, they are variously modified to subserve other functions, like respiration, food-collection and tactile sensation.

BODY WALL AND SKELETON

The epidermis is usually ciliated except in Holothuroids and Ophiuroids. The epidermis usually contains gland cells and sensory cells. The characteristic dermal ossicles vary quite greatly. They may remain scattered or may be firmly united so as to form an armour. Despite great diversities in form, they are possibly homologous in all Echinoderms. The ossicles are formed as the deposition of calcareous substances in the connective tissue matrix. The dermal plates are spiny in most cases and the spines are mainly protective in

function. They may also help in locomotion in some cases. The spines and other processes derived from them, are movably placed. In Asteroids and Echinoids, some of the spines become specialised into *pedicellariae*. The detailed structure of the pedicellariae has been described in the example part of the phylum. These are nothing but two or three spines arranged as pincers. The pedicellariae are primarily

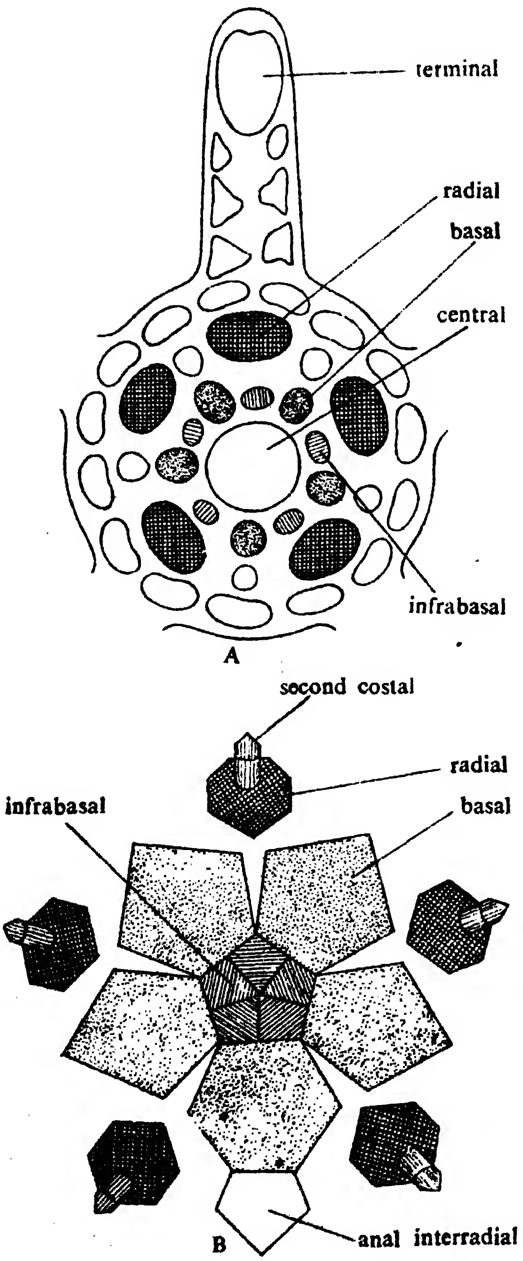


Fig. 18.27. Apical skeletal systems of *Amphiura* (A) and *Cyathocrinus* (B).

protective in function. The dermal plates are quite distinct in some Echinoderms; in others they are not clearly understandable. However, the plates are broadly distinguishable into ORAL and ABORAL PLATES. The ORAL PLATES are five in number and are interradially placed. They can be easily distinguished in the Crinoids and Ophiuroids. The ABORAL PLATES are quite distinguishable in early developmental stages (Fig. 18.27). The aboral plates, in typical cases, consist of a *central plate* which is surrounded by five radially disposed *infrabasals* and five interradially placed *basals*. Beyond the circle, five radially arranged *radials* are placed. Both the oral and aboral plates are absent in Holothurians. The infrabasals as well as the radials are lacking in Echinoids. Other details regarding the skeletal system is dealt under the different examples of the phylum.

DIGESTIVE SYSTEM

The alimentary canal in Echinoderms shows great variation in different groups. The alimentary canal becomes coiled in most forms. In Ophiuroidea and Asteroidea the alimentary canal is axial. The position of the mouth and anus varies greatly in different classes. The anus is usually excentrically placed excepting Holothurians. In Crinoids, the mouth and anus are situated on the same side of the body. The anus is lacking in Ophiuroids and in a few adult Asteroids. The alimentary canal bears various diverticula, such as *siphon* in Echinoids, *respiratory trees* in Holothurians, *cardiac* and *pyloric caeca* in most Asteroids and *intestinal diverticula* in Crinoids. Lack of separate glandular appendages is the most remarkable feature in Echinoderm anatomy.

COELOM

The coelom in the adult Echinoderms is represented as several distinct spaces. It develops from a diverticulum of the embryonic enteron. The diverticulum subsequently becomes separated from the enteron and forms a number of sacs—the *hydrocoel* and the *splanchnocoel*. The water vascular system arises from the hydrocoel and the splanchnocoel transforms into several systems of spaces:

(1) The body cavity proper or the *perivisceral cavity* develops from the right

and left posterior coelom in the larva. It has no connection with the exterior except in Crinoids where the water-pores open into it.

(2) The *axial sinus* varies greatly in development. It usually develops from the anterior larval coelom. The stone canal opens into it and communicates with the exterior through water-pores or with the coelom as in most Holothurians.

(3) The sinus system or the *perihaemal spaces*. This part develops as outpushing of the posterior and anterior larval coeloms. This part of the coelom forms a covering of the haemal channels. It consists of a circumoral space and five radially placed tubes. This system is not present in Crinoids. The aboral circular sinus is also included in this system.

The coelomic spaces have an epithelial lining which is ciliated in most places. It contains albuminous fluid with floating *amoebocytes* which are phagocytic in function. Several types of amoebocytes of different sizes and appearances have been distinguished. Another type of corpuscle with vibratile tail is also recorded in the coelomic fluid. They are designated as *vibratile corpuscles*. They set forth a constant circulatory movement of the coelomic fluid. In Holothurians, a good number of flattened nucleated cells containing haemoglobin are present.

WATER VASCULAR SYSTEM

The anatomy of Echinoderm represents a characteristic canalicular structure traversing the body These canals constitute the water vascular system. As stated earlier, the water vascular system is enterocoelic in origin and arises from the left hydrocoel. It exhibits radial symmetry from the beginning and is equally developed in all Echinoderms. This system lies just above the haemal system. It is primarily locomotory in function and also subserves the function of tactile and respiratory organs in some cases. The excretory role of water vascular system, suggested by some workers, is not yet fully ascertained.

Histological picture reveals that the canals have an inner lining of flat ciliated epithelium, a layer of longitudinal muscles, a connective tissue layer and an outermost layer of flat ciliated cells. The canals of the water vascular system contain a fluid of albuminous nature. It contains sea water and leucocytes. Existence of red corpuscles is recorded in an Ophiuroid, *Ophiactis virens*. Binyon (1962) has shown that the level of potassium in the fluid may be as much as 60% above the sea water value. Boolootian (1961) has recognised 14 different types of amoebocytes in this fluid.

The water vascular system in different classes of Echinodermata has almost the same structural organisation. It comprises of a few canals together with some appendages attached to these canals. The typical arrangement of the water vascular system is exhibited by *Asterias*. The water vascular system includes a *circumoral* canal (*circular ambulacral* or *ring canal*) situated around the mouth which gives tubular radial extensions called *radial canals*. The number of the radial canals is usually five. But the number corresponds to the number of the radii of the body. Each radial canal ends blindly at the end of the arm and gives off along its course *lateral vessels*, each joining a *tube-foot*. Each tube-foot is a hollow conical or cylindrical process with an *ampulla* and a terminal *sucker*. The junction between the lateral vessels and the tube-feet is provided with valves which assist in locomotion. The contraction of the ampullae results in the extension of the tube-feet. A short, slightly curved, cylindrical and vertically disposed *stone* or *sand canal* is present between the *madreporite* and the ring canal. The stone canal opens into the ring canal at the oral end and into the madreporic ampulla at the aboral end. The *madreporite* is a skeletal plate-like structure placed at the aboral side. It is perforated by pores, called the *madreporic pores*, which lead into madreporic ampulla or vesicle from where the stone canal starts. The stone canal is surrounded by a wider canal, called *axial sinus*, the wall of which becomes folded to form the *axial organ* or *dorsal organ* or *ovoid gland* or *heart*. The role of axial organ is not fully known.

Besides the main vessels, some appendages become associated with the system. Interradially located and connected with the ring canal, there are *polian vesicles* and *Tiedemann's bodies*. The Polian vesicles are bladder-like sacs with narrower neck. They are contractile and usually manufacture amoeboid cells. The Tiedemann's bodies

are glandular in nature and consist of a number of branched tubules. They are yellowish in colour and give origin to cells for the water vascular system.

Modifications of the water vascular system in different classes

The water vascular system is equally developed in all Echinoderms and has basically the same structural plan. In the different classes, slight deviations from the basic plan are encountered. The variations are due to their adaptations to different modes of living.

Madreporite. In Asteroidea, it is a calcareous seive-like plate and is situated aborally. The increase in number of the madreporite is observed in many Asteroidea. The number of madreporites is 3 in *Asterias capensis*, 4 in *A. tenuispina*, 16 in *Acanthaster echinites*. The madreporite is provided with many secondary water-pores. Most of the water-pores lead into stone canal and rest into the axial sinus in adults. The water-pores are many in number and develop from one primary larval water-pore. Like Asteroidea, in Echinoidea also the madreporite possesses many pores, but *Echinocyamus pusillus*, is peculiar in having only one water-pore. In Ophiuroidea, the madreporite has one water-pore, but in Ophiurae and Astrophytidae there are several water-pores. In Holothuroidea true madreporite is absent. Great variations are observed regarding the opening of the stone canal. In *Pelagothuria* it opens to the exterior by one pore and in many Elasipodidae there are 2 to 50 or more pores. But in some Elasipodidae and Molpadidae the stone canal opens into the coelom by many pores instead of opening to the exterior. In the rest of the Holothurians, the stone canal opens into the axial sinus which in turn opens to the exterior by one or more water-pores which are comparable to madreporite. The madreporite in this case may best be called as *internal madreporite*. In Crinoidea, madreporite is represented by fine water-pores on the body surface and these water-pores lead directly into the body cavity. The water-pores are recorded to be 1500 in *Antedon bifidia*.

Stone canal. Normally the stone canal is a short, slightly curved and vertically disposed cylindrical tube. It opens into the ring canal at the oral end. It is enclosed by the wall of another wide canal, the *axial sinus*. In Asteroidea, the stone canal is one and 'S'-shaped. But in *Asterias rubens*, there are two stone canals. The wall of the stone canal is provided with calcareous ossicles. Development of a longitudinal ridge-like projection makes the stone canal complicated in the different members of the Asteroidea (Fig. 18.28). The following conditions are encountered: (1) In *Echinaster purpureus*, the fold projects as a ridge into the canal. This represents the simplest condition. (2) In *Asterina gibbosa*, the free terminal end divides into two lamellae which may be coiled. This is seen in *Asterias* and *Gymnasterias*. (3) In *Astropecten*, the coiled lamellae become very complicated and extend between the walls from one side to another of the lumen. (4) In *Culcita* and *Astropecten aurantiacus*, the whole lumen becomes divided into a number of irregular chambers. In Echinoidea, the stone canal is only one and has soft membranous wall devoid of calcareous matter. In *Cedaris*, the wall of the stone canal is provided with calcareous deposit. The stone canal has an ampulla below the madreporite. In Ophiuroidea, the stone canal is devoid of calcareous deposition and opens in one of the oral plates. In *Trichaster elegans*, there are five stone canals. In *Ophiactis virens*, the stone canals are many. In Holothuroidea, the stone canal is mostly single but in some cases it may be more than one. The number of accessory stone canal is also variable. Its walls are provided with calcareous matters. The opening of the stone canal shows greatest variation, particularly in Holothurians. The stone canals in all Holothurians are attached to body wall. In *Pelagothuria*, the stone canal opens to the exterior by one or many pores. This also is true in many Elasipodidae. In *Thyone*, the stone canal is branched. In some Elasipodidae and Molpadidae the stone canal ends blindly and opens internally into the coelom by many pores as in the genus *Elasipoda*. In Crinoidea, stone canal as such is absent. Numerous tubes, without calcareous deposits in their walls, emerging from the ring vessel are the representatives of the stone canals of other groups.

Axial sinus and Axial organ. The *axial sinus* is variously developed in different Echinoderms. It is quite distinct from

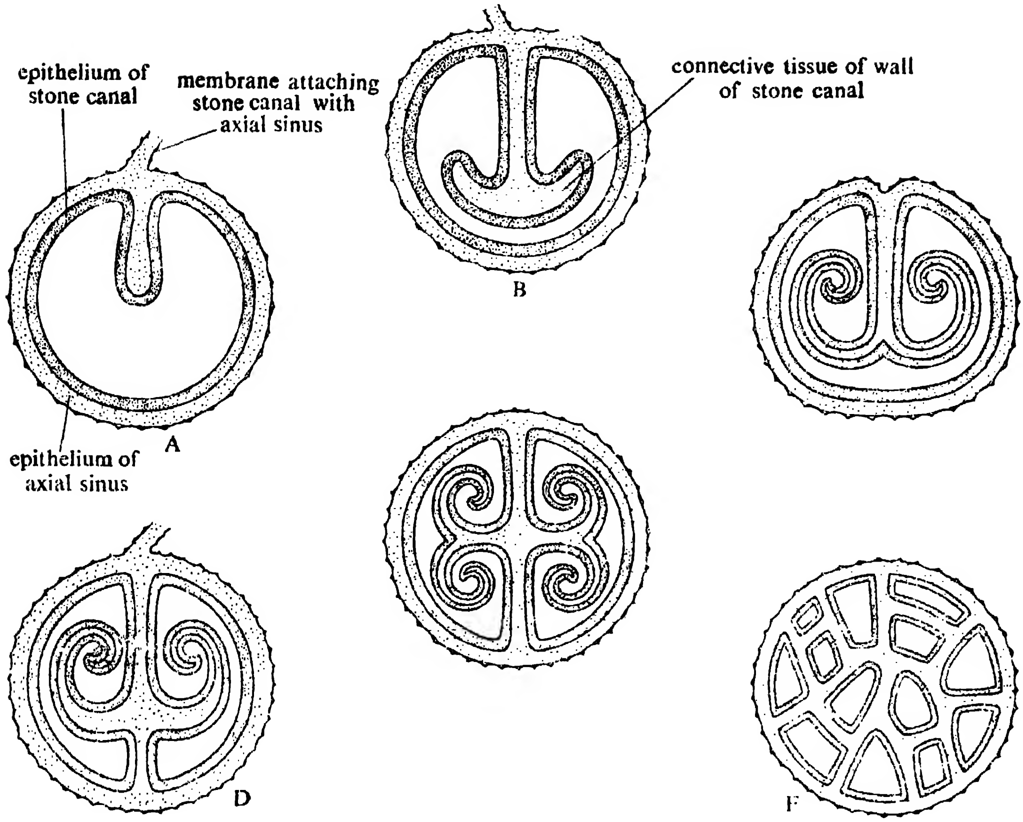


Fig. 18.28. Sectional view of stone canal in various Asteroids. A. *Echinaster*. B. *Asterina*. C. *Asterias*. D & E. *Astropecten*. F. *Culcita*.

the perivisceral cavity in adult excepting some Holothurians and Crinoids. The axial sinus is inconspicuous in Asteroids, very small in Echinoids and Ophiuroids. The *axial organ*, a fold from the wall of the axial sinus, is present in all Echinoderms excepting Holothurians. The axial organ comprises connective tissue and cells of germinal rudiment. In Echinoids the axial sinus ends blindly and communicates with the stone canal. In Crinoids, the portion of the coelom, into which the tubes from the ring vessel open, represents the axial sinus. The axial organ occupies the axis of the body. It consists of anastomosing canals embedded in connective tissue.

Ring canal and Radial canals. The *ring canal* is a constant structure in all Echinoderms and is situated round the mouth. It gives tubular prolongations along the radii called *radial canals* or *radial vessels*. In Asteroidea, the ring canal is pentagonal and is situated in the buccal membrane (peristome). It is communicated with the exterior through the stone canal and axial sinus. In Echinoidea, the ring canal is situated at the upper end of the jaws and gives five radial vessels. In Ophiuroidea, the condition is same as in Asteroidea. In Holothuroidea, the ring canal is situated around the oesophagus and the five radial vessels extend towards the oral end and again proceed aborally along the radii of the body. The radial vessels end blindly and the terminal tentacle, characteristic of Asteroidea and Echinoidea, is absent. The number of radial vessels are five. They are absent in Synaptidae. In case of Crinoidea, the terminal tentacles are absent and the radial vessels end blindly.

Lateral vessels and Tube-feet. The radial vessels give *lateral vessels* to the tube-feet. The tube-feet are cylindrical processes and their cavities are continuous with the water vascular system. The tube-feet possess ampullae at their inner ends

and suckers at the terminal ends. The ampullae are present in all echinoderms, except Ophiuroidea and Crinoidea. In Crinoidea, terminal suckers are absent and the tube-feet are sensory and respiratory in function. In many Astropectinidae, each tube-foot is provided with two ampullae. In all the members of the Asteroidea the tube-feet are provided with well-developed suctorial disc-like expansions. In Echinoidea, the tube-feet show variations. In Endocyclica, the terminal ends of the tube-feet are suctorial and supported by calcareous rings. In Cidaridae and Echinothuridae, small oral tube-feet project from the perforations of the ambulacral plates which are olfactory in nature. In Clypeasteroids, the tube-feet are broad and the walls are devoid of calcareous bodies. They help in respiration. The cylindrical tube-feet which are suctorial and provided with calcareous rings, are locomotory in function. But in Spatangoids, the tube-feet vary quite greatly which are due to their functional activities. The tube-feet without suckers are respiratory in function; with suckers and calcareous ring are locomotory in function; with expanded terminal disc and filaments around the mouth as the tactile organ; rosette feet act as prehensile organs and seize food from the surroundings. In Ophiuroidea, the orientation of the lateral vessels and the tube-feet is same as in Asteroidea, but they are devoid of ampullae and are exclusively sensory in function. In Holothuroidea, lateral branches from the radial vessels go into the tube-feet as well as into the tentacles. Some lateral branches also emerge from the radial vessels and end blindly in the body wall. Ampullae are present in the tube-feet and in the tentacular canals. The tentacular canals are devoid of ampullae in Elasipodidae where they arise directly from the ring canal. Among the Crinoidea, in *Antedon*, each lateral branch from the radial vessel supplies three tube-feet. The tube-feet have ampullae. They are purely respiratory and sensory in function.

Polian vesicle and Tiedemann's bodies

The ring canal possesses bladder-like *polian vesicles* and gland-like *Tiedemann's bodies*. In Asteroidea, the number of polian vesicles varies greatly. They are totally absent in *Asterias rubens* and *A. glacialis*. There are cases where two or many polian vesicles may be present in each interradius as seen in *Astropecten*. In this case, a few vesicles open into the ring canal by one common stalk (Fig. 18.29). The Tiedemann's bodies are attached to the ring canal and are usually two in each interradius excepting that containing the madreporite where only one is present. Amongst Echinoidea, in most Endocyclica, a small spongy outgrowth in each interradius is present which is supposed to be the polian vesicle. There are five Tiedemann's bodies in Echinoidea. In Ophiuroidea, in each interradius excepting that of stone canal there is a polian vesicle. In *Ophiactis virens*, besides two or three polian vesicles opening in each interradius, there are many tubular *canal of Simroth* (supposed to be respiratory in function). In Holothuroidea, usually one large polian vesicle is present. In some exceptional cases more than one polian vesicles may be present. In Crinoidea, the polian vesicle and Tiedemann's bodies are absent.

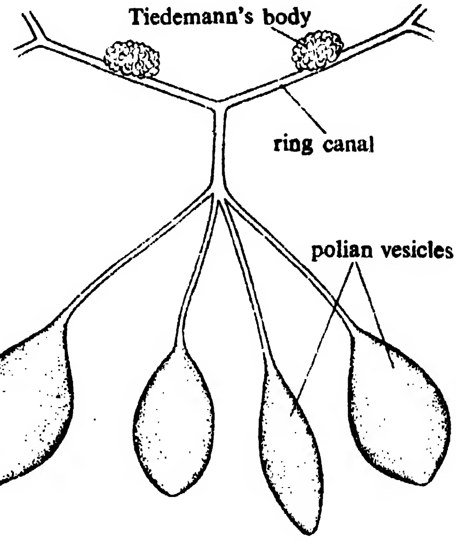


Fig. 18.29. Cluster of polian vesicles of *Astropecten*.

Functions of the water vascular system

The main function of the water vascular system is to help in locomotion. Echinoderms having suctorial tube-feet can adhere to the substratum temporarily. Non-suctorial tube-feet help in respiration. The brush-like tube-feet in Spatangid Echinoderms work as olfactory and tactile organs. In some Spatangids the tube-feet are prehensile in nature.

HAEMAL SYSTEM OR BLOOD LACUNAR SYSTEM

The existence of blood vascular system in Echinoderm cannot be definitely stated. The haemal system in echinoderm plays the role of blood vessels. But the fluid contained in this system does not show any circulatory movement. This system comprises a peculiar connective tissue of doubtful nature. The haemal system is present in all the Echinoderms and is well-developed in Asteroidea and Ophiuroidea. The haemal system is greatly reduced in Crinoidea. The haemal system is almost same in all the classes of Echinoderm excepting a few minor modifications regarding positional changes of the madreporite. In Echinoderms, the haemal system consists of an *oral ring* with five *radial canals* which terminate blindly at the aboral end. The oral ring gives off a *gastro-intestinal system* which becomes quite complicated in most of the cases. Conspicuous development of the gastro-intestinal system suggests that its primary function is nourishment.

EXCRETORY SYSTEM

The process of excretion in Echinoderms is not fully known. There is no specialised organ in Echinoderm which can be assigned to be excretory in function. With all probabilities, some organs associated with the water vascular system or with the axial sinus are responsible for the elimination of the nitrogenous waste products.

NERVOUS SYSTEM

The nervous system is modified in different classes of Echinoderm. This system consists of (1) Ventral nervous system; (2) Deep oral nervous system and (3) Apical nervous system. The VENTRAL NERVOUS SYSTEM is well-developed in different classes of Echinoderms. This system is placed superficially and consists of diffused subepithelial nerve plexus which becomes concentrated in the different parts of the body. It is sensory in nature and supplies nerves to the integument, tube-feet and gut. The ectodermal part of the plexus is called *ectoneural* and the endodermal part is designated as *endoneural*. The ectoneural plexus becomes concentrated around the mouth as the *circumoral nerve ring* which in turn gives *radial nerves* along the radii. In Echinoidea, Ophiuroidea and Holothuroidea, the circumoral nerve ring and radial nerves are placed in the wall of the *epineural canal*. The ectoneural plexus prolongs into the tube-feet, spines and pedicellariae. The endoneural plexus is well formed in Asteroidea and forms *perioesophageal nerve ring* around the mouth opening. The DEEP ORAL NERVOUS SYSTEM consists of two nerve cords (Lange's cords) in each radius. These two nerve cords lie in the ectoneural system and are separated from the radial nerve by connective tissue layer. They are mesodermal derivatives and motor in nature. The APICAL NERVOUS SYSTEM consists of a cord situated in the mid-dorsal line of the body. It develops from the dorsal peritoneum. This system is best developed in Crinoidea and is altogether absent in Holothuroidea. It is exclusively motor in nature and mesodermal in origin.

The SENSE ORGANS are mainly the tactile organs. The tube-feet are exclusively sensory in function in majority of the Echinoderms. The terminal tentacles are sensory units in starfishes. They are tactile organs situated one at the tip of each arm. This *spines* are also highly sensitive. The *pigmented spots* situated at the tip of the arms of Asteroidea are probably photosensitive. The *shining spots* on the skin of an Echinoid, *Diadema*, are also assigned to be visual in function. The *otocysts* of Holothuroidea and *Sphaeridea* (modified spines) of Echinoidea are the organs of special sense. Besides these structures, numerous neurosensory cells are scattered all over the body which are either tactile organs or chemoreceptors.

REPRODUCTIVE SYSTEM

Sexual reproduction

In Echinoderms, the sexes are separate except a few hermaphroditic forms, such as *Asterina gibbosa*, *Cucumaria frondosa* and *Amphiura squamata*. The reproductive organs in Echinoderms are quite peculiar in nature. MacBride has shown that the reproductive organs are composed of cells derived from coelomic epithelium. The reproductive organs are connected with a cellular cord called *genital rachis*. Existence of the genital rachis in Holothuroidea is questionable. A cord having germ cells passing along the genital duct towards the body wall, is comparable to the genital rachis of others.

The reproductive organs consist of tufts of branched, paired and interradially disposed bodies. They open directly on the surface. In Crinoidea, the reproductive organs are contained in pinnules which are devoid of an opening to the exterior. The mode of discharge of genital products in this case is not known. In Asteroidea, Ophiuroidea and Echinoidea, the gonads are oriented pentamerously in the interradii. In Asteroidea, there are five pairs of gonads which open usually on the aboral surface. In a few genera under the class Asteroidea, the gonads are numerous in number. In Holothuroidea there is only one branched gonad which may be imperfectly divided into two. But the single duct from the gonad opens to the exterior on the surface near the mouth. The reproductive cells, when ripe, are discharged directly into the sea.

Asexual reproduction

Asexual reproduction by fission is observed in many Echinoderms, especially in Asteroidea, Ophiuroidea and Holothuroidea. In Asteroidea and Ophiuroidea, a line of fission passes through the central disc, while in Holothuroidea it passes transversely along the axis of the body. Spontaneous reproduction by fission is reported in Asteriid genera (*Coscinasterias*, *Sclerasterias*, *Stephanasterias*, *Linckia* and *Allostichaster*). Crozier (1920) found that in the first animal asexual reproduction is confined to summer months and normal gametic reproduction occurs in winter months.

REGENERATION

The echinoderms are endowed with remarkable power of regeneration of their lost parts by autotomy (self-mutilation). The power of regeneration is relatively poor in Echinoidea, but in Asteroidea and Ophiuroidea, it is quite extensive. Regeneration of whole body from a single arm is recorded in starfishes. If arms or a portion of the central disc is extirpated or lost mechanically they can regenerate the lost portions. In Crinoidea and Holothuroidea the power of regeneration is so profound that the internal organs or portions of them are capable of being regenerated.

DEVELOPMENT

In all Echinoderms, the eggs are fertilized in sea water. Almost all the echinoderms pass through characteristic free-swimming and bilaterally symmetrical larval stages (Fig. 18.30). In *Asterina gibbosa*, free-swimming larva is absent as the development occurs in the brood of the mother. In a few holothurians, development occurs in the coelom and in the genital tubes in *Chiridota contorta*. Development in *Stichaster nutrix* takes place in the stomach of the mother.

The Echinoderms, where free-swimming larval forms are present, have small eggs. But in forms where development occurs in brood or body cavity or in stomach, the eggs are relatively large in size owing to greater quantity of yolk. The fertilized eggs undergo total cleavage (holoblastic) and a large number of cells (blastomeres) are produced. These cells arrange themselves so as to form a hollow one-layered *blastula*. The blastula by invagination at its one pole transforms into a *gastrula*. The invaginating cells form the endoderm and the outer layer becomes the ectoderm. The archenteron communicates posteriorly with the exterior through the *blastopore*. Mesenchymal networks in the form of nucleated protoplasmic processes are formed between the ectoderm and endoderm. These networks give rise to muscles, connective tissues and calcareous ossicles. The archenteron acquires a new opening to the exterior at the antero-ventral side, called larval mouth. As development progresses, the anus is shifted ventrally and the cilia present all over the body become localised into definite bands. The disposition of the ciliated bands differs in different larval forms.

Fate of larval mouth and anus. The fate of the larval mouth and anus varies quite greatly among the different classes of the Echinodermata. In Asteroidea and Echinoidea, both of these close and the adult mouth and anus are formed anew. In Holothuroidea, both of these persist in adults. In Ophiuroidea, anus is lacking in adults but the larval mouth persists. In Crinoidea, both larval mouth and anus are absent.

Basic larval forms

Dipleurula larva. The dipleurula form (Fig. 18.30A) is reached during development and is characterised by its bilaterally symmetrical egg-shaped body. The ventral concave side bears the mouth and

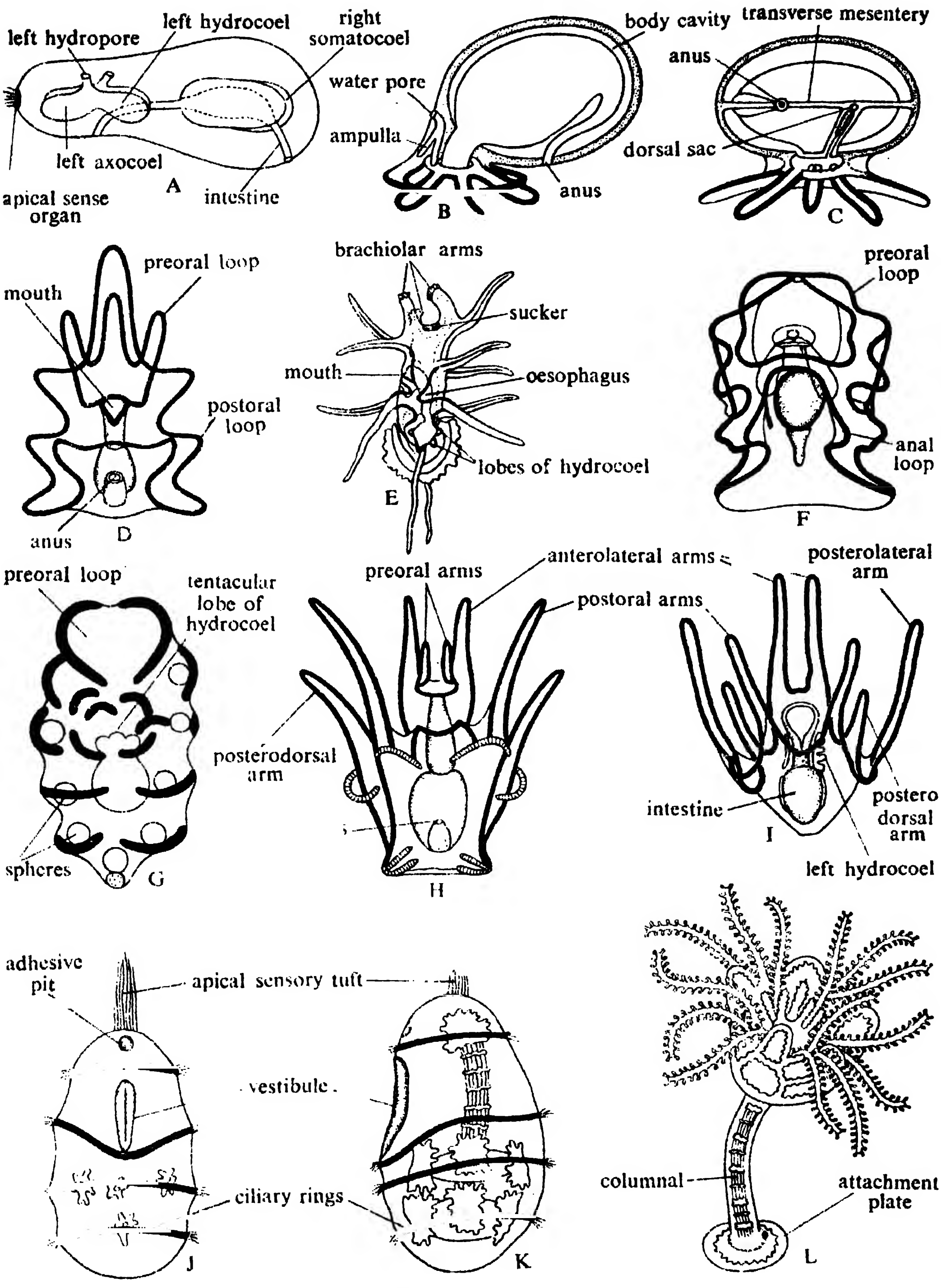


Fig. 18.30. Different larval forms in Echinodermata. A. Hypothetical *Dipleurula* larva. B. Bilateral stage of *Pentactula* larva. C. *Pentactula* larva after torsion of radial position. D. *Bipinnaria* larva. E. *Brachiolaria* larva. F. *Auricularia* larva. G. Transitional stage from *Auricularia* to *Doliolaria* larva. H. *Echinopluteus*. I. *Opiopluteus*. J. *Doliolaria* larva of *Antedon*. K. Late *Doliolaria* larva of *Antedon*. L. *Pentacrinoid* stage of *Antedon*.

is encircled by a circumoral ciliated band. The anus is disposed ventrally. This Dipleurula form is regarded by many as the hypothetical ancestral form of Echinoderm, as this form is universally present. The Dipleurula concept was first propounded by Bather (1900). The major changes involved in other Echinoderm larvae are due to differential disposition of the ciliated bands.

Pentactula larva. This larval stage is regarded as the next evolutionary step of the Dipleurula larva. This concept has been supported by Semon (1888), Burry (1895), Hyman (1955) and many others. The Pentactula larva (Fig. 18.30 B, C) has five tentacles around the mouth. The hydrocoel is separated from the rest of the coelom to form the future water vascular system.

Larval diversities

It is presumed that from those basic larval forms other varieties of Echinoderm larvae have evolved in time and space.

Bipinnaria larva. This type of larva (Fig. 18.30D) is characteristic of the class Asteroidea. It possesses two ciliated bands —the preoral and the postoral. The preoral ciliated band surrounds the preoral lobe of the larva. The preoral lobe is highly developed. The postoral ciliated band appears to be longitudinally placed and forms a complete ring between the mouth and anus. The bipinnaria larva bears a close resemblance with the auricularia larva of Holothurians. The body of bipinnaria larva is externally bilaterally symmetrical but subsequently the internal structures assume asymmetry. The preoral and postoral ciliated bands are continued over a series of prolongations of the body, called arms. The name and number of the arms developing from preoral and postoral ciliated bands are as follows:

Name of the arms		*Number*
1. Postero-lateral	..	Two
2. Postoral	..	Two
3. Postero-dorsal	..	Two
4. Antero-dorsal	..	Two
5. Preoral	..	Two
6. Ventro-median	..	One
7. Dorso-median	..	One

The preoral and ventro-median arms develop from the preoral ciliated band and the rest of the arms develop from the postoral ciliated band. The arms are provided with muscles and are contractile in nature. The antero-lateral arms are absent. These two ciliated bands are regarded to have arisen from a single ciliated band (as in auricularia) which becomes subsequently divided. This is evidenced by *Asterias rubens* and *A. glacialis* where these two ciliated bands remain initially dorsally connected. In artificially cultured bipinnaria larvae, sometimes a single ciliated band is seen. In *Asterina gibbosa*, the typical bipinnaria larva is slightly modified and it moves by the action of the cilia present in the *larval organ*. In the genus *Luidia*, the bipinnaria larva is peculiar in having a slender long anterior part which terminates into two wide arms. This larval form is named by Sars (1835) as *Bipinnaria asterigera*.

Brachiolaria larva. This type of larva (Fig. 18.30E) is present in Asteroidea and is regarded as a modified form of bipinnaria larva. It possesses the following special features. There are three additional arms which are not ciliated in their courses except in *Bipinnaria papillata*. These arms are called the *brachiolar arms* and are beset with warts to help in temporary adhesion. These arms are devoid of calcareous rods and have prolongations from the coelomic cavity. The bipinnaria stage is followed by the brachiolaria stage in all Asteroids but direct evidence is only furnished in two cases, e.g. *Asterias glacialis* and *A. vulgaris*. In *Astropecten*, *Asterina gibbosa*, the brachiolaria stage is absent and the bipinnaria larva metamorphoses directly into adults.

Auricularia larva. The externally bilaterally symmetrical larva (Fig. 18.30F) is present in Holothuroidea and is characterised in having a single longitudinal ciliated band. The preoral lobe is very well-formed. There are no calcareous rods, being replaced by spheroids or star-shaped or wheel-like bodies. In certain forms, e.g. *Auricularia stelligera* and *A. sphaerigera*, elastic spheres of unknown consistency are present.

Doliolaria larva. The larval form is observed in Holothuroidea. The auricularia larva transforms into a barrel-like body with five ciliated bands which subsequently break into pieces. (Fig. 18.30G). This particular stage is also designated as *pupa stage*. During metamorphosis into an

adult form, the ciliated bands disappear and further changes occur.

In *Cucumaria planci*, the auricularia stage is absent and the embryo transforms directly into the doliolaria stage. In *Cucumaria frondosa*, *C. saxicola*, *Psolus phantapus*, both of the larval stages may be absent. In *Holothuria floridana*, there is no larval form and the embryo develops directly into a young Holothuroid.

Pluteus larva. This larval form (Fig. 18.30 H, I) can be regarded as a modification of the auricularia larva of Holothuroid. Like the auricularia larva it has a single ciliated band, but it possesses long arms with ciliated bands at the margin. It has comparatively smaller preoral lobe. The postanal part of the body is quite well-developed. The arms are also supported by calcareous rods. The pluteus larvae are of two kinds: (1) *Ophiopluteus*—in Ophiuroidea. (2) *Echinopluteus*—in Echinoidea. Both the larval forms possess the postoral arms, antero-lateral arms, postero-lateral arms and postero-dorsal arms. But they differ in detail which are summarised in Table 1—Echinodermata.

TABLE 1—ECHINODERMATA

Comparative Account of Ophiopluteus and Echinopluteus

Structures	OPHIOPLUTEUS	ECHINOPLUTEUS
Postero-lateral arms	Largest, present in all forms and project forward.	May be absent; when present, project backwards.
Preoral and antero-dorsal arms.	Absent.	Present.
Unpaired posterior arm	Absent.	Present in Spatangid Echinoids where the ciliated band is not continued.
Ciliated epaulettes and ciliated lobes.	Absent.	Present in advanced larval forms of *Echinus* and *Sphaerechinus*. The ciliated epaulettes are four in number and situated at the basal regions of the postero-dorsal and postoral arms. The *ciliated lobes* or *auricular appendages* are cutaneous prolongations at the posterior end and are two in number.
Calcareous skeleton	Divided into two halves, each arises from one calcification point.	Skeleton formation proceeds from five to six calcification points.

The typical ophiopluteus may be absent, in certain forms. The arms are small in *Ophiopluteus metschnikoffi* and *O. claparedei*. In *Ophionotus hexactis* the ophiopluteus lacks arms. The larva may be elongated and without ciliated bands. The skeletal rods are usually absent; if present, only one in number. This condition is observed in *Ophiopluteus annulatus*, and *O. oblongus*.

Antedon or Yolk larva. This particular larva is also called *doliolaria* larva (Fig. 18.30 J, K). This larval stage is present in Antedon and it has many structural peculiarities. It has a barrel-shaped body with

slightly flattened ventral side. It is free-swimming and exhibits bilateral symmetry. The ciliated bands are in the form of four or five separate transversely placed bands encircling the body. In *Antedon bifida*, there are four bands. In *Antedon adriatica* and *A. mediterranea* there are five bands. A tuft of cilia with stiff sensory hairs springs from a thickened ectodermal patch called apical neural plate which is comparable to that of *Tornaria* larva of Balanoglossus. The anterior ciliated ring is ventrally incomplete. There is a ciliated depression or larval mouth which is ventrally placed between the second and third ciliated rings. A small *adhesive pit* develops between the first and second ciliated rings by which the larva adheres to the substratum. The internal structures become rotated at an angle of 90° from the ventral to the posterior side.

Cystidean or Pentacrinoid larva. This larval stage is also present in Crinoids. The anterior end of the antedon larva, after attachment, is prolonged into an elongated narrow stalk and the free end becomes broader (Fig. 18.30L). The ciliated depression becomes a closed ectodermal vesicle which is gradually shifted to the free end. The floor of the depression is perforated by mouth and with the disappearance of the roof, the mouth and the tentacles become exposed. This particular phase is called *Cystidean* or *Pentacrinoid* stage. This stage resembles closely the adult *Pentacrinus*. The stalk in this form develops from the preoral lobe. This stage is quite similar to that of Asteroidea excepting that it lacks circumoral vessel.

AFFINITIES OF ECHINODERMATA

The echinoderms, especially their larval forms, attract the attention of many Zoologists due to the presence of many striking similarities between themselves and between different other groups of animals.

A number of early workers have established affinities between the trochophore larva of annelids and some echinoderm larvae on the basis of the presence of similar ciliated bands and some other superficial similarities. But these affinities are not based on any scientific ground because cleavage pattern is spiral in annelida but radial in echinoderms; coelom formation is schizocoelic in annelids but enterocoelous in echinoderms.

Some superficial similarities are also noted in between the early developmental stages of Brachiopoda and Echinodermata. The similarities are: (i) cleavage is holoblastic, (ii) blastula is a coeloblastula, (iii) the coelom is enterocoelous in the members of the class Articulata of phylum Brachiopoda, (iv) the members of class Articulata have free-swimming larval stage. However, these affinities are only superficial.

The most convincing affinities are noted between the echinoderms and the chordates. Hence many workers regarded the echinoderms to be the nearest group to the chordates. However, modern workers do not support the contention and they hold that the echinoderms and the chordates diverged separately from a common basic ancestor. The affinities are discussed below:

(1) Mesodermal skeletal substance is present in both.

(2) Presence of infra-epidermal nervous system in hemichordata.

(3) The perforations on the calyx of carpoid echinoderms are compared with pharyngeal gill-slits of Amphioxus.

(4) Needham (1932) has tried to show a relationship between these two groups by analysing biochemical evidences. Invertebrates have the phosphogen in the form of arginine phosphate whereas chordates usually have creatine phosphate. But the echinoids among echinodermata and hemichordates among Chordata have both arginine phosphate and creatine phosphate.

(5) Wilhelmi (1942) has shown similarities between the two groups by serological tests as well.

(6) Cleavage is radial, holoblastic.

(7) Blastopore changes into anus.

(8) Enterocoelous mode of coelom formation.

(9) The similarities between adult echinoderms and chordates are very few, but the affinities between the larval forms are highly notable. Metschnikoff (1869) tried to show the following affinities between the tornaria larva of Balanoglossus and the bipinnaria and auricularia larvae of the echinoderms: (i) free-swimming and bilateral symmetrical larvae in both, (ii) transparent body with similar ciliated

bands, (iii) enterocoelous coelom with similar disposition, (iv) similar location of mouth and anus, (v) the madreporic vesicles in bipinnaria are thought to be homologous with heart vesicle of Balanoglossus.

De Beer and Garstang hold that the tornaria larva, the dipleurula and pluteus larvae are living relics from a very remote period when the echinoderms and chordates were not diverged. The neotenous theory propounded by Garstang in 1894

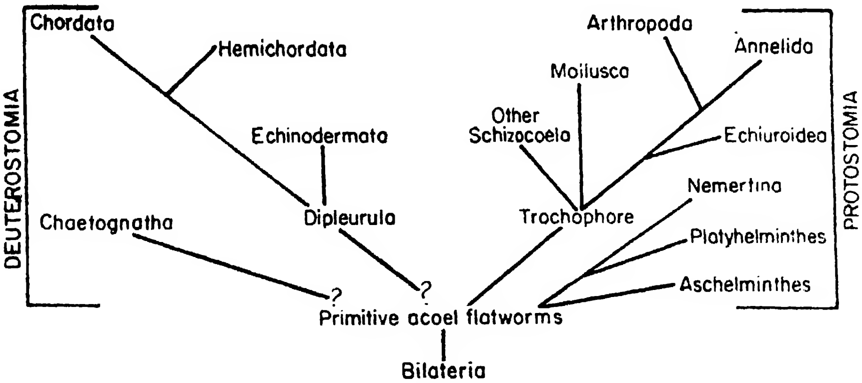


Fig. 18.31. Phylogeny of chordate (L. H. Hyman's view).

Bather (1900) claimed common ancestry of hemichordates and echinoderms from the dipleurula larva. The genealogical tree given in 1957 by Anderson and Guthrie and the phylogenetic tree given in 1948 by L. H. Hyman in colaboration with Prof. W. K. Fischer who also supports the same idea. (vide the phylogenetic trees (Figs. 18.31 and 18.32).

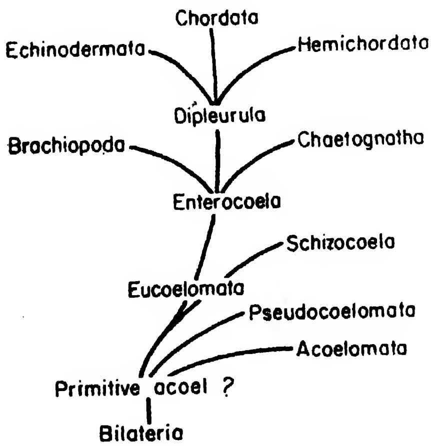


Fig. 18.32. Phylogeny of chordates (Guthrie and Anderson's view).

Muller and Bateson again claimed that the tornaria larva and dipleurula larva had evolved from a common ancestral source.

holds that the chordates arose from some neotenous form of auricularia larvae. The adoral ciliated band of auricularia presumably functions to convey food particles into the oral aperture, and for this it has been converted to the floor of the pharyngeal cavity. Garstang suggests that endostyle was derived from this loop of the adoral band of the auricularia larva. An atrium was developed in course of time to protect the gills. The fish-like swimming larva of tunicates is held by him to be formed from the development of muscles along the sides of the elongated body. The ciliary bands were then pushed upwards and subsequently rolled up with the underlying nerve plexus to form the neural tube. Fig. 18.33 shows Garstang's idea of derivation of the protochordate from echinoderm larva.

But all these traditional contentions have been objected by modern workers like Berrill (1955), Fell (1963), and Pawson. They deny the ancestry of chordates from any form of echinoderms and they also deny the relationship between the tornaria larva and the echinoderm larvae. Many counter-arguments have been put forward by them. Protocoel is unpaired in Balanoglossus, but paired in echinoderms. Extant echinoderms lack pharyngeal gill-slits. Bipinnaria larva lacks telotnoch. Then, the tornaria larva has a characteristic apical plate with eye-spots. Fell, Berrill and many

others hold that the affinities between tornaria and echinoderm larvae are not based on any phylogenetic relationship but are merely due to larval convergence for similar mode of life. In Fell's own words "It therefore follows that within the phylum (Echinodermata), larval similarities do not indicate toxonomic affinities. Extrapolating beyond the phylum, so as to deduce taxonomic affinities on the basis of resemblance between auricularia and tornaria, is therefore inadmissible. The unreliability of larval structure in the echinoderms as a guide to phylogenetic affinity is further illustrated by the occurrence of divergent patterns of development

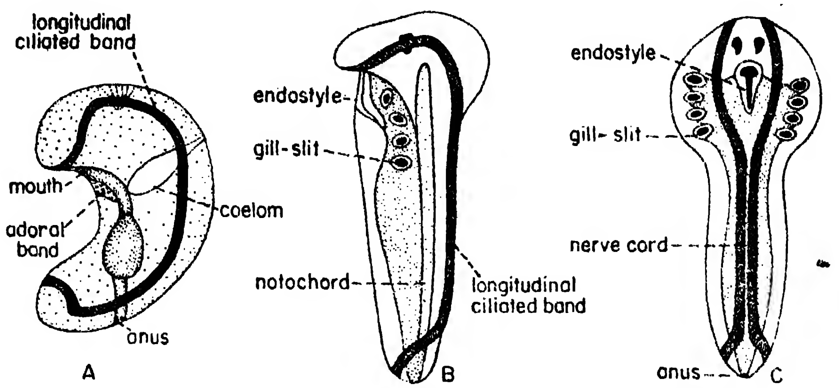


Fig. 18.33. Showing the sequences of derivation of the protochordate from echinoderm larva, possibly the auricularia (after Garstang). A. Auricularia larva (side view). B–C. Protochordate. B. Side view, C. Dorsal view.

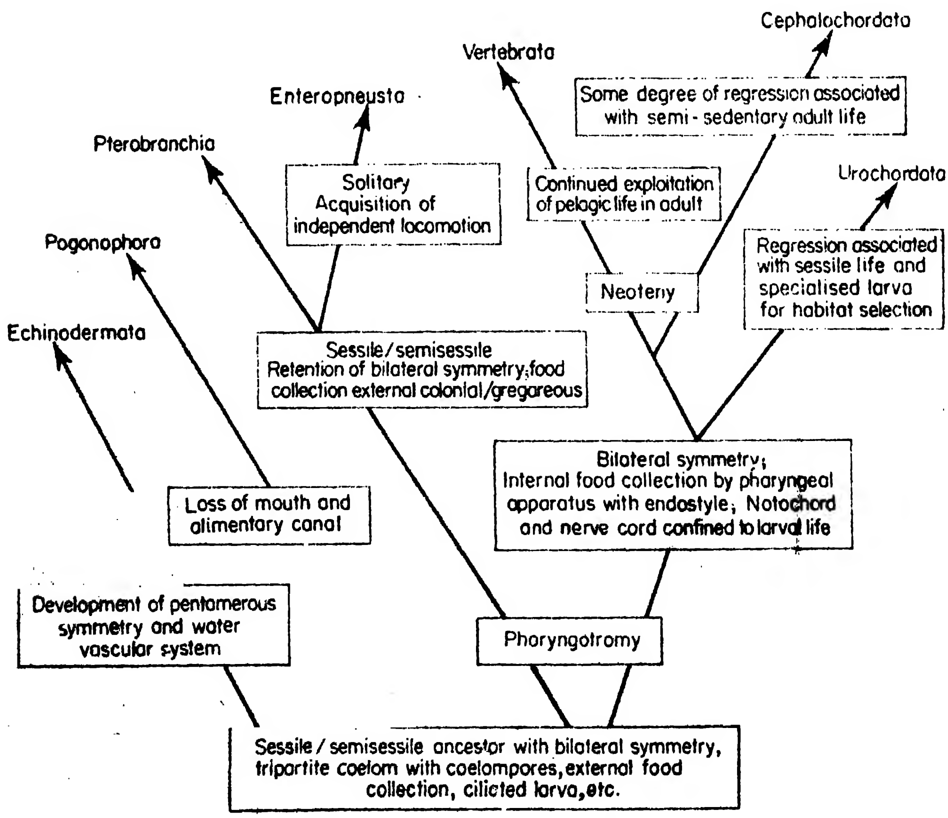


Fig. 18.34. Showing the phylogenetic relationship of Denterostomia (after Barrington, 1965).

within related groups (e.g. Ophiuroidea), and the occurrence of convergent patterns of development among unrelated groups (e.g. Asterozoa, Echinozoa, Crinozoa)."

The presence of similar biochemical substances may not necessarily speak of any phylogenetic relationship and may be due to convergence for similar modes of physiological activities. Moreover, creatine phosphate has been found to occur also in other animals phylogenetically remote from the chordates, such as in sponges (Robin, 1954) and in many polychaetes (Hobson and Rees 1955).

Barrington has summarised the work of other workers like Berrill ('55), Bone ('60), Carter ('57), Marcus ('58) and Whitear ('57) and has proposed that the echinoderms, the pogonophores, the hemichordates and the rest of the chordates arose separately but directly from a common bilaterally symmetrical, sessile or semi-sessile ancestor with tripartite body and coelom, ciliated larval stage and ciliary mode of feeding from external source (Fig. 18.34).

PHYLOGENETIC CONSIDERATIONS

The phylum Echinodermata exhibits variety of forms. They differ from one another by specialised features. Despite apparent diversities, they possess striking similarities in development and in their basic structural organisation. They have many common features: (1) The eggs are small and yolked. (2) The cleavages are holoblastic and radial. (3) Gastrulation involves invagination. (4) The blastopore has posterior location. (5) The coelom is developed as the outpockets from the archenteron (enterocoelic in origin). (6) The larvae are free-swimming and have bilaterally symmetrical bodies. (7) In all adult Echinoderms, adjacent to the epidermis there exists calcareous ossicles constituting the skeleton of the body. The disposition of the plates varies in different forms.

These common features suggest the idea that all Echinoderms have emerged out of a common ancestral stock where such structures were present. It is also regarded that the ancestral forms with bilateral symmetry, are the forerunners of the group. Although fossils were quite abundant since Precambrian time, no tangible explanation can be obtained regarding the ancestry of Echinoderms from the palaeontological angle. The presence of superficial radial symmetry in adult Echinoderms leads to many confusing issues. Because of radial symmetry, some Zoologists have tried to link them with the Coelenterates. But the presence of bilateral larval forms and underlying bilateral symmetry in some adult Echinoderms suggest that they have arisen from bilaterally symmetrical ancestor and the radial symmetry in adult is a secondary acquisition (Fig. 18.35). With all probabilities, some unknown Precambrian forms with bilateral symmetry are to be regarded as the ancestor of Echinoderms. Heterostelea with heavy endoskeleton and lack of radial symmetry represents the transitional stage and forms a sort of bridge between the bilateral ancestor and pentaradiate adult Echinoderms. Two exactly opposite views exist on this particular issue. According to the first concept the hypothetical ancestor is the Dipleurula larva but other school holds that the Pentactula larva is the ancestor.

Dipleurula concept. The view that the Dipleurula larva was the hypothetical ancestral form of all Echinoderms was propounded by Bather (1900). This larval form has following features: (*i*) Bilaterally symmetrical body with preoral lobe, (*ii*) Absence of skeletal formations, (*iii*) Ventrally placed mouth and anus, (*iv*) Presence of three paired sacs (axocoel, hydrocoel and somatocoel) with two water-pores. It has been imagined by many workers that this larva holds the key of Echinoderm ancestry. But it was not possible to explain the derivation of some vital Echinoderm features, viz. the water vascular system and its development from the coelom. According to Bather, water vascular system originates as three ciliated grooves which become five by the subsequent subdivision of the two lateral grooves. The available interpretations on the origin of the water vascular system are not supported by embryological data. Embryological studies showed that the water vascular system arose as the outgrowths of the body wall in the form of tentacles.

Pentactula concept. The pentactula concept of the Echinoderm ancestry has certain advantages over the dipleurula stage. This idea was first conceived

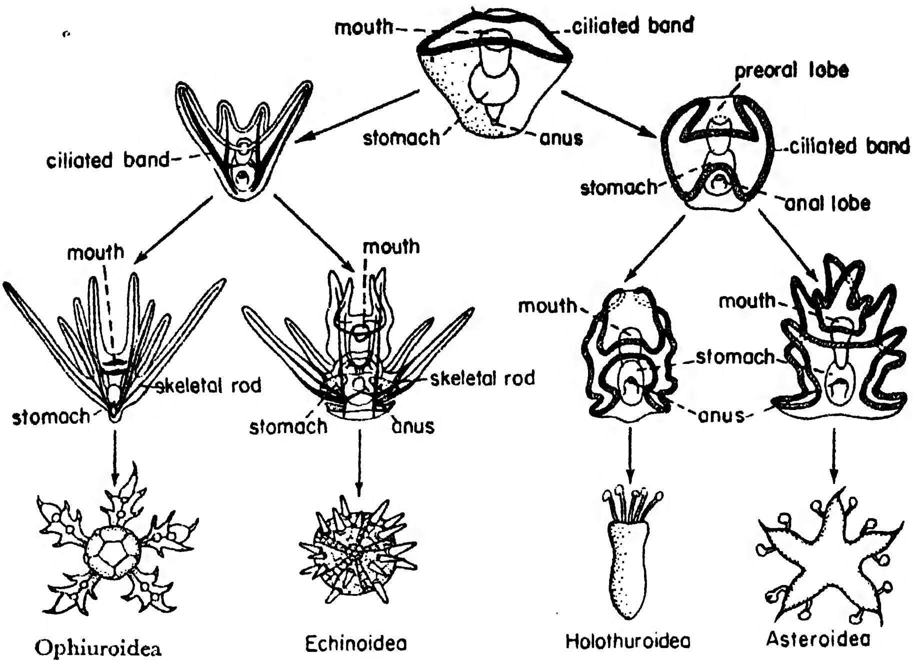


Fig. 18.35. Showing the development of radially symmetrical adult echinoderms from the bilaterally symmetrical larva (after Parker and Haswell).
Note that (i) the Ophiuroidea and Echinoidea are closely related and (ii) Holothuroidea and Asteroidea are closely related.

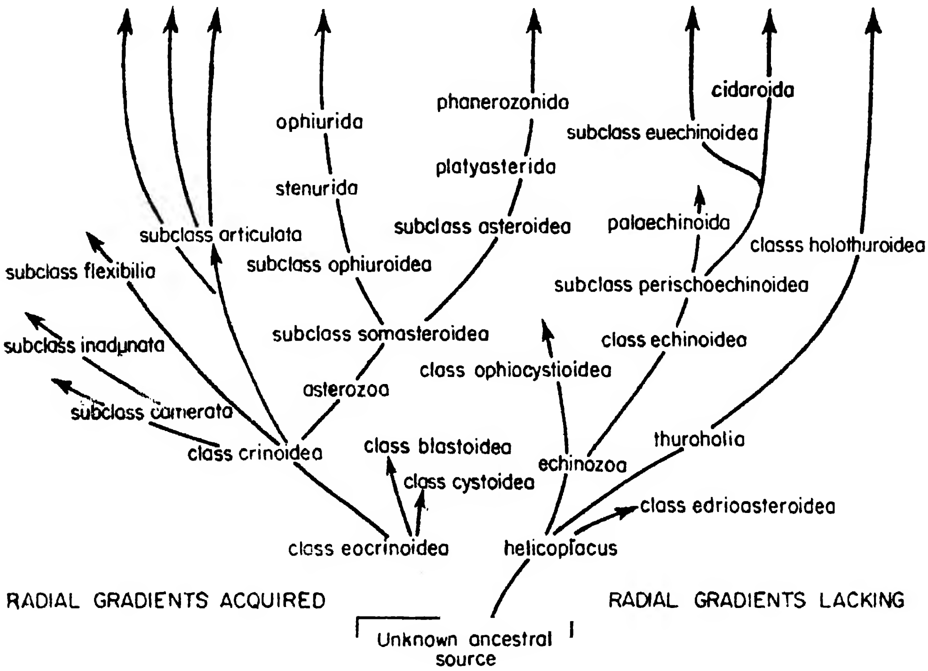
by Semon (1888) and later developed by Burry (1895), Hyman (1955) and many others. According to them the Pentactula larva occupies the next evolutionary rank over the dipleurula larva. The pentactula larva has five tentacles around the mouth and the hydrocoel becomes separated from the rest of the coelom to form the water vascular system. The recent inclination is to hold the view that the Echinoderms have descended from a free-swimming common ancestor, possibly the pentactula larva, and from the pentactula stage onwards the divergence has actually started.

As regards the interrelationships between the different groups of the phylum Echinodermata, it was suggested by early workers that the subphylum Eleutherozoa consisting of the sea-stars, sea-urchins, sea-cucumbers and brittle-stars has arisen from the subphylum Pelmatozoa which included the crinoids and others. Early workers also suggested that the sea-stars and sea-cucumbers had many common features, specially at the larval stages. Both of them were held to be related to crinoids more closely and they had possibly diverged very early from the Pelmatozoan ancestor. On the other hand, ophiuroids and echinoids were regarded to be closely related with each other due to the presence of striking similarities in between their larval forms and also due to the presence of similar sterols (Bergmann, 1949) and creatine phosphate (Yudkin, 1950; Florkin, 1952) in both ophiuroids and echinoids. Such similarities led early workers to establish a relationship between ophiuroids and echinoids and both were regarded to have diverged subsequently from the Pelmatozoan ancestor. Eminent palaeontologists like, Bather, Marcus, Mortesen held that all the classes of the subphylum Eleutherozoa arose from Edrioasteroidea, an extinct group of Pelmatozoans, because of similar disposition of ambulacral pores, flexible theca, stalkless body and many other features. Shrock and Twenhofel suggested that only the holothurians and echinoids have evolved from Edrioasteroidea.

But recent workers on other line have totally discarded the views of all early workers. They claimed that ophiuroids and echinoids are closely related due

to striking similarities between the ophiopluteus and echinopluteus larvae and that asteroids and holothurians are related due to the presence of auricularia larva in both the groups (see Fig. 18.35) are shown to be in total disagreement with the results obtained from morphological and palaeontological studies. Recent researches show that the apparent re-

uroidea). It is also indicated that both ophiuroids and asteroids are closely related to each other and they have certainly descended from common ancestors akin to the fossil Somasteroidea. The somasteroids and crinoids again had a common ancestry. On the other hand Holothuroidea and Echinoidea had a common ancestry.



18.36. Showing the phylogenetic relationship between different groups of echinoderms (after Parker and Haswell).

lationship between ophiuroids and echinoids in one hand and between asteroids and holothurians on the other are due to convergent larval evolution. Modern workers advocate that the apparent dissimilarities between ophiuroids and asteroids are due to divergent larval evolution. Fell showed that the echinoderms show convergent patterns of development among unrelated groups (Asterozoa, Echinozoa and Crinozoa) and divergent patterns of development among related groups (Ophi-

Thus modern researches suggest that the larval affinities cannot act as a guide in establishing the phylogenetic relationships between different classes of surviving echinoderms. Moreover, the superficial biochemical similarities between ophiuroids and echinoids may also be a result of physiological convergence for similar mode of living.

The origin of and interrelationship between different classes of echinoderms are shown in Fig. 18.36.

SUMMARY

1. The echinoderms constitute a unique group of invertebrates having radially symmetrical pentamerous body in an adult. The larval forms exhibit bilateral symmetry. The radial symmetry in adult is a secondary acquisition and has possibly evolved from bilateral ancestor.

2. The echinoderms have very ancient origin and the fossils were amply recorded since Cambrian.

3. The members of the phylum are exclusively marine and inhabit intertidal zones to all depths of the sea. They have almost a cosmopolitan distribution.

4. The echinoderms are gregarious animals and move in groups. They are mostly free-swimming forms except the Crinoids which may remain fixed.

5. The body is covered over by characteristic spines, warts or calcareous ossicles of mesodermal origin.

6. The body is differentiated into oral and aboral surfaces. The body surface presents five radiating ambulacra (representing radii) with wide interveninng interambulacra (representing inter-radii).

7. The coelom is quite extensive and enterocoelic in origin. The coelom is filled with a fluid containing various types of coelomocytes.

8. The alimentary canal is either simple or a coiled tube and presents a number of peculiar features. The position of anus varies quite greatly in different groups of Echinoderms. The anus may be absent or it may be located on the oral surface in some forms.

9. A characteristic coelomic derivative, water vascular system, is present which performs a number of vital functions. This system is fundamentally similar in all Echinoderms. The minor deviations observed in different groups are the result of different adaptations.

10. Presence of tube-feet or podia is a peculiar character and they subserve locomotion, capture food, help in respiration and also act as sensory organs.

11. There is no specialised organ for respiration. Respiration is performed by a variety of structures, viz. papulae, oral branchiae, genital bursae, respiratory trees.

12. The haemal or blood lacunar system is present in all echinoderms.

13. Definite excretory organs are lacking.

14. The nervous system is primitive and comprises of circumoral nerve ring and radial nerves. The brain is lacking. The sense organs are very poorly developed.

15. Reproduction is sexual and most of them are unisexual. Gonads are very simple.

16. Fertilization is external and the development is accompanied by a variety of bilateral, ciliated and free-swimming larval forms.

17. Echinoderms are classified into two subphyla and ten classes, of which five are extinct and five are living. *Asterias*, *Echinus*, *Holothuria*, *Ophiura*, *Sollasina*, *Placocystis*, *Mesocystis*, *Cadastar*, *Antedon*, *Cystaster*, are some of the common examples of the phylum.

CHAPTER 19

Minor Invertebrate Phyla

Other than the ten major invertebrate phyla already described, many minor invertebrate groups have been recorded. The animals included under these groups have peculiar anatomical organisation and exhibit structural similarities with diverse animals. Because of this fact, the relative biological status of these groups in the animal kingdom has remained ever controversial. In this chapter, a brief survey of some such important groups has been made (Fig. 19.1) and to avoid controversies all of them have been given the rank of phyla. They are broadly categorised into two groups—the noncoelomates and coelomates.

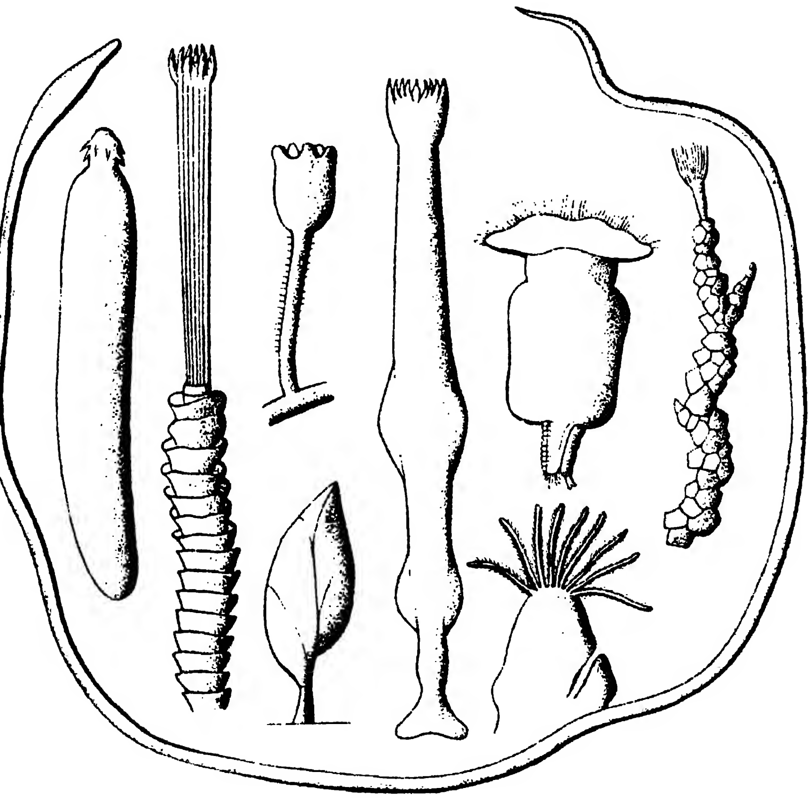


Fig. 19.1. A few invertebrate animals having controversial biological status.

MINOR NON-COELOMATE PHYLA

This group includes four distinct forms — *Endoprocta*, *Rotifera*, *Nematomorpha* and *Acanthocephala*, where coelom is absent.

PHYLUM ENDOPROCTA (CALYSSOZOA)

This group includes a number of minute sedentaric animals. They are either solitary or colonial forms (Fig. 19.2A). Superficially they resemble the Hydroidea and Bryozoa. Formerly this group was included under Bryozoa. But recent workers have excluded them from Bryozoa and placed them under the phylum Endoprocta. All the forms are marine excepting the fresh-water form, *Urnatella*. The representatives of this group are *Pedicellina*, *Loxosoma*, *Myosoma* and others.

The stalked cup-like body is called *calyx*. The calyx bears circlet of tentacles at the free edge. The cavity of the cup is called *vestibule* and it contains both mouth and anus. The alimentary canal is curved to form a U-shaped tube (Fig. 19.2B). The space between the body wall and the alimentary canal is filled up with

parenchyma. The excretory system consists of a pair of excretory organs which are ciliated intracellular tubes. Each excretory tube begins with a flame cell. The two excretory tubes may open separately or may unite to form a common duct

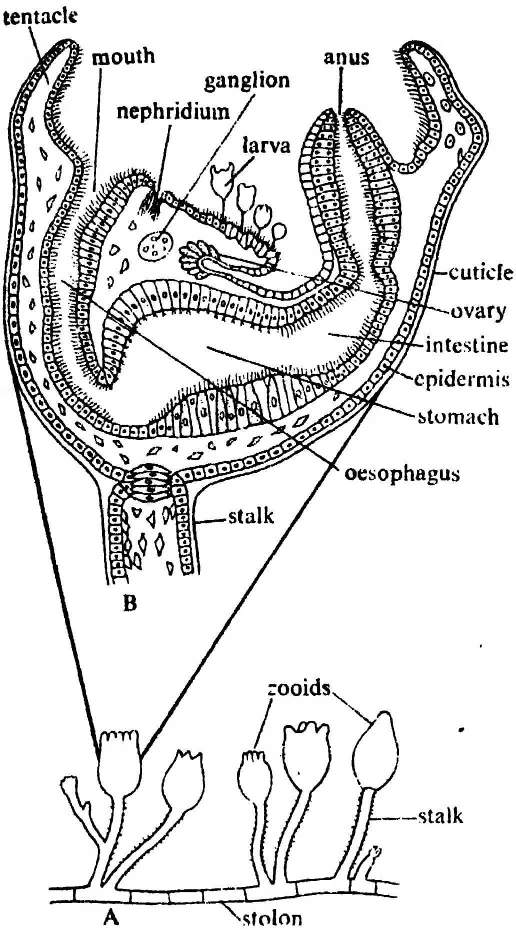


Fig. 19.2. Structures of *Pedicellina*. A. Part of a colony. B. Enlarged sectional view (saggital section) of a calyx.

opening into the cloaca. The nervous system is represented by a suboesophageal ganglion which is bilobed in *Loxosoma*. The sexes may be united or separate. In the solitary form (*Loxosoma*), the body is divided into a *calyx* and a *stalk* which possesses foot-gland at the base. In the colonial forms (*Pedicellina* and *Urnatella*) the body of each zooid is separated from the stalk by a *diaphragm*. Asexual reproduction occurs by budding from any part of the body and the buds remain attached to the parent which leads into colony formation.

The development is indirect. The larva is ciliated and free-swimming. After a brief free-swimming phase the larva attaches itself to the free surface of other animals and transforms into adult.

PHYLUM ROTIFERA

The members of this phylum are microscopic animals, commonly called the 'wheel-animalcules'. The name of the Phylum Rotifera came from two latin words, *rota*=wheel and *ferre*=to bear. The biological status of rotifers was long a debated issue. They were grouped with the ciliated protozoa for long times, but closer examination revealed their metazoan organisation. They are virtually the smallest metazoa and include a large number of species. Although different in minute details, all of them are built on the same fundamental plan. The descriptive account of a typical genus, *Brachionus* is outlined below.

EXAMPLE OF THE PHYLUM ROTIFERA—*BRACHIONUS*

Habit and Habitat

Brachionus is a fresh-water inhabitant, and feeds on microscopic organisms brought by ciliary action.

External structures

Brachionus exhibits distinct sexual dimorphism. The females are well-formed and are larger in size in comparison to their male counterparts (Fig. 19.3 A, B). The male is different from female in having a number of peculiar features. It is a minute degenerate form where the alimentary canal is lacking. All other organs, excepting the reproductive organs, are greatly reduced. The trochal disc is simple in males. The following description implies to a female Brachionus.

The body is divisible into *trunk* and *tail* or *foot*. The trunk is encased in a transparent flexible *lorica* which is provided with spines. The tail is wrinkled and terminates into two small processes. Mouth is situated on the ventral side of the trunk. The dorsal side is convex. The anterior end of the body projects out as *trochal disc* which is a transverse disc-like body beset with cilia in the margin. The trochal disc helps in locomotion by rotation. A pair of *cement glands* are present in the tail. The secretion of the cement glands

enables the animal to attach to the substratum temporarily. It has a remarkable power to survive desiccation.

Body wall and body cavity

The body wall is composed of a *cuticle*, *epidermis* and *subepidermal muscles*. The epidermis is syncitial and contains very few gland cells. The body cavity is a pseudocoel.

Digestive system

The food of Brachionus includes minute organisms (specially protozoans) and organic debris which are brought into the mouth by ciliary action. The *mouth* is situated in a depression on one side of the trochal disc. The mouth leads into a very short *buccal cavity*. The buccal cavity opens into a round muscular chamber called the *pharynx* and *mastax*. The mastax is a complicated structure which varies in shape and size. Several types of mastax are encountered in rotifers, but the particular type of mastax present in Brachionus is of *malleate type*. The mastax is a peculiar apparatus characteristic of the rotifers. It is composed of masticatory parts (*trophi*) and musculature.

Typically the trophi consists of two chief components: (A) *Incus* and (B) *Malleus*. The incus is again made up of a single basal piece called *fulcrum* and two lateral triangular pieces called *rami*. The malleus is composed of two toothed pieces of *unci* and two pieces of elongated hammer-like *manubria*. These different components are operated by sets of well-developed muscles. About 2–7 salivary glands are situated in the mastax wall and the ducts, specially of the ventral pairs, open anterior to the trophi.

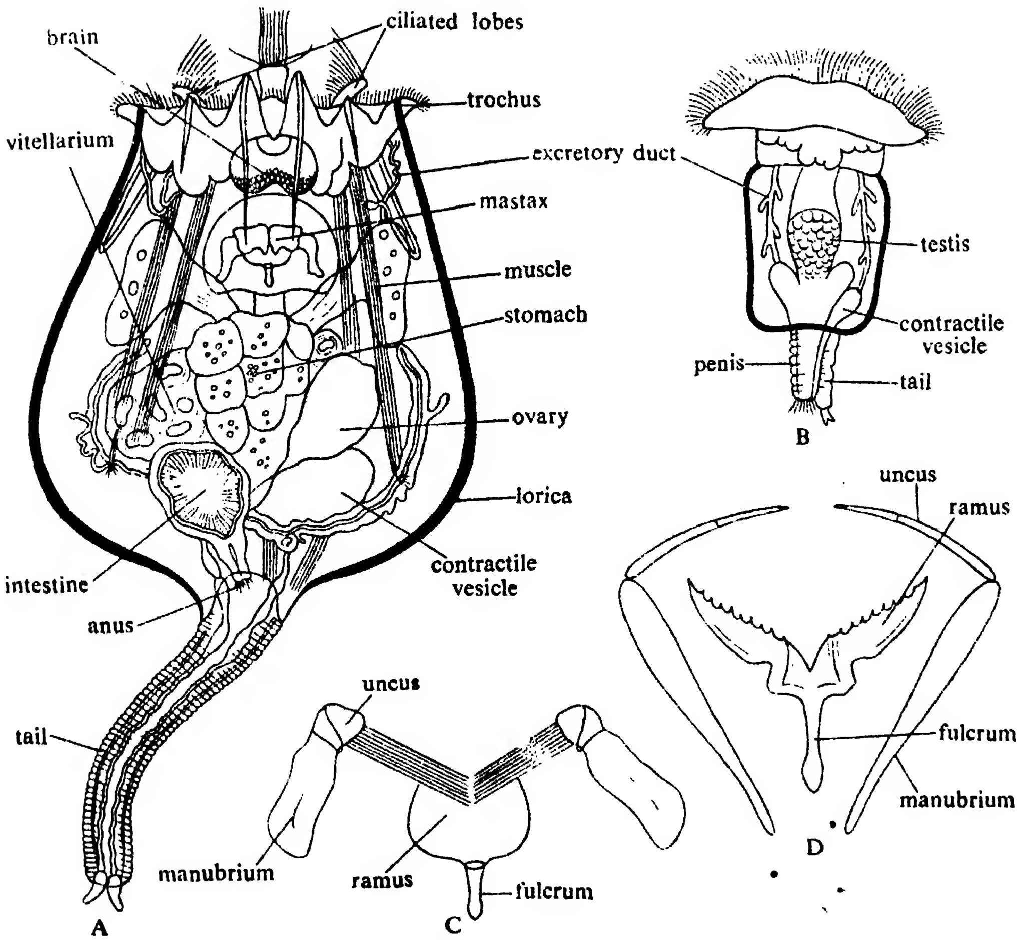


Fig. 19.3. A. Dorsal view of a female *Brachionus*. B. Dorsal view of a male *Brachionus*. Note that the internal structures of both male and female are visible through transparent lorica. C. Structures of the malleate type of mastax. D. Structures of the forcipate type of mastax.

Due to different feeding adaptations, the mastax becomes modified in different species. The varieties of mastax found in different rotifers have great taxonomic significance, because they are regarded as the criteria for classification. Of the types of mastax, the most important ones are: I. **Malleate type.** This type of mastax is found in *Brachionus*, *Epiphanes* (Fig. 19.3C). This type represents the primitive condition and all the components in it are relatively short and strongly built. The rami are devoid of teeth but the unci bear a few prong-like teeth. It assists in grasping as well as in chewing the prey. II. **Forcipate type.** This type is found in *Dicranophorus* (Fig. 19.3D). All the pieces are elongated and slender. The rami are curved and toothed. The rami and the fulcrum together form a forceps-like structure. The sharply pointed tips of the rami are intimately associated with the rod-like pointed unci. The forcipate type of mastax can protrude through the mouth to grasp the prey. Other than these two major forms, there are many other varieties, namely *submalleate*, *virgate*, *cardate*, *incudate*, *ramate*, *uncinate* and *fulcrate* types.

The pharynx of Brachionus is connected with spacious thick-walled sac-like *stomach* by a short *oesophagus*. A pair of digestive glands are associated with the anterior end of the stomach. From the stomach a short *intestine* emerges which passes into an oval *cloaca*. The cloaca communicates to the exterior through the *cloacal aperture*. This aperture is located mid-dorsally towards the posterior end. The inner wall of the stomach and intestine is ciliated.

Circulatory system

Brachionus lacks a definite circulatory system.

Excretory system

The excretory system comprises of a pair of *nephridial tubes* or *excretory canals* which open posteriorly into a *contractile vesicle* or *urinary bladder*. The excretory canals are situated one on each side of the alimentary canal. The contractile vesicle opens into the *cloaca*. The cavity of the nephridial tubes is intracellular in nature.

Nervous system

The nervous system consists of large bilobed ganglion (*Brain*) situated on the dorsal side of the body above the pharynx. From the brain, many nerves emerge out to supply the various organs of the body including the sense organs.

Sense organs

Chief sense organs are present in the forms of very small *eye-spots* or *ocelli* on the dorsal aspect of the brain. The other sense organs are one dorsal and two lateral *tactile rods* or *feelers*.

Reproductive system

The sexes are separate and the sexual dimorphism is well-marked. The female is comparatively larger than the male. The female reproductive system consists of an *ovary* which is communicated to the cloaca by an *oviduct*. The ovary is also designated as the *germarium* and is connected with a large *vitellarium*. Three types of eggs are produced. These are: (*a*) female-producing 'summer eggs', (*b*) male-producing 'summer eggs' and (*c*) 'winter eggs'—which have impervious resistant shell. Both the 'summer eggs' develop parthenogenitically and the 'winter eggs' after fertilization, develop into females. The male reproductive system consists of a very large *testis* which leads into a duct opening into a dorsally placed *penis*.

Development

The zygote divides into micromeres and macromeres by unequal holoblastic cleavage. Gastrulation occurs in epibolic fashion. The embryo transforms directly into adult.

CLASSIFICATION

The rotifers are divided into four orders:

Order *Ploima*

The tail is usually forked and retractile. The ciliated disc acts as locomotor organ. The lorica may be present or not. Examples: *Polyarthra*, *Hydatina*, *Brachionus*, *Pedalion*.

Order *Bdelloida*

The cilia of the disc help in locomotion and the tail is very small and forked. *Rotifer* and *Philodina* are the examples.

Order *Rhizota*

The tail is non-retractile and truncated. It helps in fixing with the substratum in adult. The typical representatives are *Melicerta* and *Strephanoceros*.

Order *Seisonida*

The example of the order is *Paraseison*. It is a parasitic form with reduced trochal disc. An elongated foot with a perforated disc is present. The body is slender and ringed.

HISTORY

Leeuwenhoek (1703) first discovered rotifers with his newly invented microscopes. Linnaeus and Lamarck regarded rotifers as protozoa. But recent workers like Remane and Mayers placed the rotifers under a separate and independent phylum.

PHYLUM NEMATOMORPHA

This group includes a number of thread-like elongated animals belonging to two families: the *Nectonematidae* and the *Gordiidae*. They are free-living in sexual phase and are parasitic in asexual stage in the body cavity of Arthropods.

The family *Gordiidae* is exemplified by *Gordius* (Fig. 19.4A). It is a fresh-water or terrestrial form. The outer surface of the body is covered with a *cuticle* (Fig. 19.4B). The muscles are made up of *epithelio-muscular cells*. The body encloses four canal-like

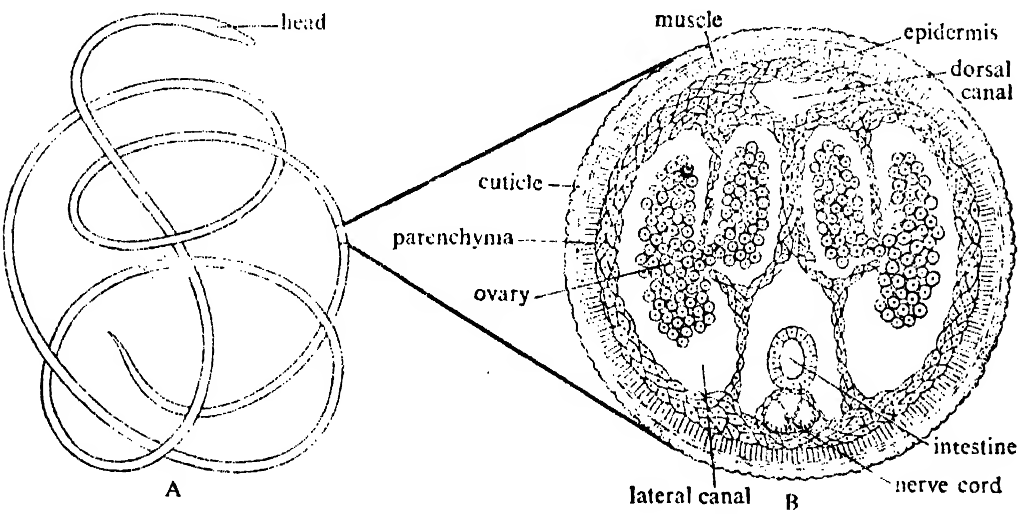


Fig. 19.4. A. An entire *Gordius*. B. Transverse section of a female *Gordius*.

cavities one mid-dorsal, one mid-ventral and two lateral in position. These cavities are separated by *parenchymatous partitions*. The alimentary canal is placed in the mid-ventral canal and the lateral cavities contain reproductive apparatus. The nervous system is represented by a greatly thickened *pharyngeal nerve ring* which is continued posteriorly as a *ventral nerve cord*. The excretory organs are absent and the sexes are separate. Complete degeneration of the alimentary canal is encountered in the sexual stage.

The family Nectonematidae is represented by the genus *Nectonema* which is constructed on the same structural plan as *Gordius*, but differs in minute details. In *Nectonema* two rows of bristles are present on the side of the body. The reproductive apparatus is simpler than that of Gordius and the ovary is unsegmented. *Nectonema* is marine.

AFFINITIES

Since their discovery, rotifers have a very uncertain systematic status. Rotifers exhibit superficial similarities with many invertebrate groups, namely Arthropoda, Annelida, Platyhelminthes and Nemathelminthes. The annelidan relationship of rotifers as advocated by Hatschek (1878) is based on structural resemblance between Trochophore larva of annelids and a peculiar rotifer, *Trochosphaera*. But recently, such similarities are regarded as a case of coincidence without having any phylogenetic significance. Rotifers exhibit many structural resemblances with Platyhelminthes. But following peculiarities of Rotifers, like absence of anus (in male), presence of continuous subepidermal muscle and epidermal nerve plexus, etc. do not justify the relationship. Considering all these features, rotifers are given the status of a phylum under non-coelomate metazoa.

PHYLUM ACANTHOCEPHALA

This phylum includes a large number of parasitic worms. The most typical forms are *Acanthocephalus*, *Neoechinorhynchus*, *Gigantorhynchus*. They are parasites in the intestine of different vertebrates ranging from fish to mammals. The anterior end of the cylindrical body is produced into an extensible *proboscis* beset with rows of numerous chitinous recurved *hooks* (Fig. 19.5). Two club-shaped structures called

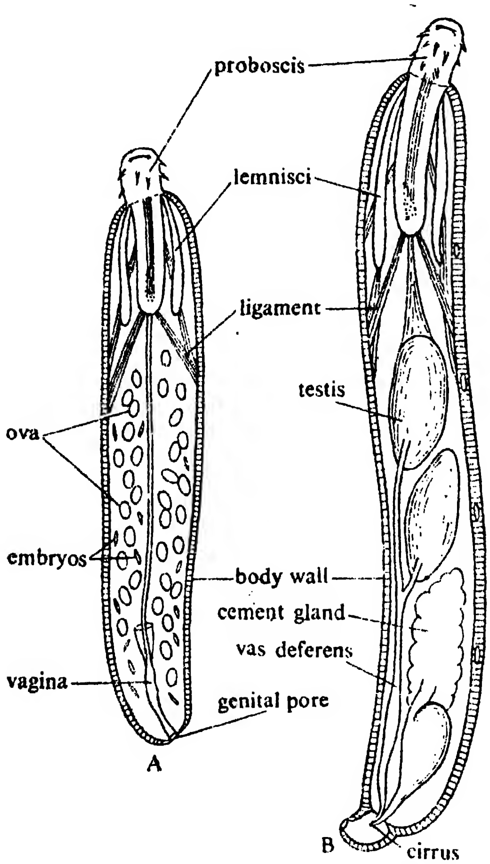


Fig. 19.5. Structures of *Acanthocephalus*, showing the disposition of internal organs. A. Male. B. Female.

lemnisci are hanging at the sides of the proboscis. A distinct *neck* between the proboscis and the *trunk* is present in certain forms. There is no aperture in the body excepting the *gonopore* at the posterior end of the body. The alimentary canal is totally absent. Two *longitudinal vessels* are present in the body wall which probably help in absorption and distribution of nutrition. A single large *nerve ganglion* is situated at the base of the *proboscis*. Sense organs are lacking. The reproductive organs occupy almost whole of the body cavity. A pair of excretory organs is present in the posterior side of the body cavity. Single *median excretory duct* opens into the *oviduct* in the female and into the *ejaculatory duct* in the male.

The sexes are separate. There are two oval *testes* which remain connected with a suspensory ligament. Similarly *ovary* is also connected with the suspensory ligament. A group of mature *ova* remain free in the body cavity.

The early phase of development takes place in the body cavity. The embryo is encased within a sac and the anterior end is provided with hooks. At this stage the embryo is extruded from the intestine of the host along with the faeces. Further development is only possible if the embryo is swallowed by an intermediate host. The intermediate host in all the forms are some Arthropods. After reaching into the intestine of the intermediate host, the chitinous membranes dissolve and the embryo undergoes further development. The embryo either remains fixed to the intestinal wall or passes out through the intestinal wall and migrates into the body cavity. If the intermediate host is taken by the permanent host, attainment of adult size and sexual maturity are achieved.

CLASSIFICATION

The phylum Acanthocephala is divided into three orders: *Archiacanthocephala*, *Palaeacanthocephala* and *Eocanthocephala*.

Order *Archiacanthocephala*

The spines on the proboscis are concentrically arranged. Protonephridia are present. Examples: *Gigantorhynchus*, *Macracanthorhynchus*.

Order *Palaeacanthocephala*

The spines are alternately arranged on proboscis. Protonephridia are lacking. Examples: *Acanthocephalus*, *Polymorphus*.

Order *Eocanthocephala*

The spines are radially arranged. Protonephridia are absent. Examples: *Neoechinorhynchus*, *Octospinifer*.

MINOR COELOMATE PHYLA

The coelomate members belonging to this group are either *Enterocoelous* or *Lophophorate*.

THE ENTEROCOELOUS COELOMATES

The Chaetognatha and Pogonophora are the groups which possess features of enterocoelous coelomates but at the same time exhibit peculiar features of their own.

PHYLUM CHAETOGNATHA

Chaetognatha constitutes a group of bilaterally symmetrical pelagic animals commonly called 'arrow worms or glass worms'. They have elongated slender bodies and the length usually varies from 40 mm to 100 mm. The chaetognaths form a very small group consisting of six genera such as *Sagitta*, *Spadella*, *Pterosagitta*, *Bathyspadella*, *Krohnittella* and *Eukhrohnia*. All the genera have similar structural organisation and the typical genus, *Sagitta* is described below to provide an idea of the group.

EXAMPLE OF THE PHYLUM CHAETOGNATHA – *SAGITTA*

Sagitta is the principal genus of the phylum Chaetognatha. It has almost a cosmopolitan distribution.

Habit and Habitat

Sagitta is a marine planktonic animal which lives throughout the world. It can swim very slowly and most of the time it floats on the surface of the sea. The fins help in floatation. Sagitta is a predaceous form and captures small planktonic animals as food by head armature. It takes food mostly at night. Sagitta exhibits diurnal migration. It comes to the surface at night and descends down during daytime. This migration results possibly as a reaction to light or temperature.

External structures

Sagitta has an elongated torpedo-like, bilaterally symmetrical body (Fig. 19.6A). The body is divisible into three parts—*head*, *trunk* and *tail*. The head is more or less triangular in outline and is separated from the trunk externally by a constricted region called *neck* and internally by a coelomic septum. The head bears four rows of teeth, one pair of *anterior teeth* and another pair of *posterior teeth*. These teeth help in food capture. Posterior to the teeth on the dorsal side of the head, there exists a pair

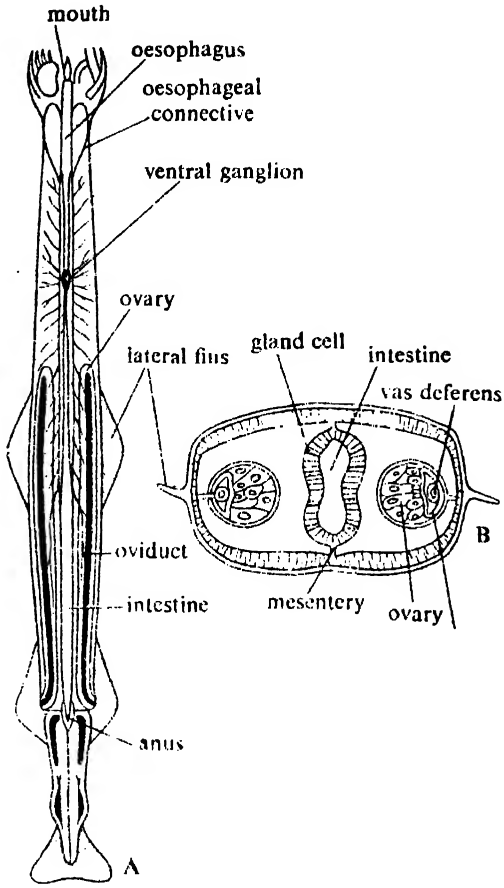


Fig. 19.6. A. Ventral view of an entire *Sagitta*. B. Transverse section of *Sagitta* passing through trunk region.

of *vestibular organs* and a glandular depression called *vestibular pit* behind the vestibular organs. A pair of pigmented *eye spots* are present on the dorsal surface of the head. There is a depression at the centre of the ventral side of the head called *vestibule* which leads into a longitudinal slit called *mouth*. On the lateral side of the mouth there are 4–14 *grasping spines* (*seizing jaws* or *prehensile spines*). These are operated by powerful muscles and help in the capture of prey. The head is covered over by a *hood* on the dorsal side. This hood is fin-like extension of the body with coelomic cavities. The hood is attached ventrally near the neck region. The hood forms a

protective device over the food-catching apparatus. The trunk is slightly broader towards the middle region and is provided with two pairs of *lateral fins*. The fins are thin and transparent extension of epidermis of the body wall. The fins are devoid of muscles and act as the floating organ. The trunk is internally demarcated from the tail by a coelomic septum behind the anus. The tail is provided with a *caudal fin*.

Body wall

The body wall is composed of an outer *epidermis* which secretes a thin *cuticle* (Fig. 19.5B). The epidermis consists of epidermal cells, the shapes of which may vary at different regions. In Sagitta, a peculiar structure, called *corona ciliata* or *ciliary loop* is present at the anterior end as a dorsal strip of modified epidermis. It forms a ridge over the epidermis proper where two or three rows of cells bear long fine cilia. Beneath the epidermis, a thin *basement membrane* exists upon which the epidermis rests. The body wall musculature consists of straited muscle layer which forms two dorsolateral muscular bands. In the head region, transverse as well as oblique muscles are also present. The histological organisation of the muscle resembles closely with the muscles of the nematodes.

Coelom

The nature of the coelom is not properly known in Sagitta, although a distinct space is present between the body wall and the alimentary tube. In the embryonic stage, coelom develops by enterocoelous method but its subsequent development is stopped at later stages. As a consequence, the homology of the adult coelom remains disputed. The head coelom is separated from the trunk coelom by a coelomic septum and the trunk coelom is also demarcated from the tail coelom by a similar coelomic partition. Both the trunk and tail coeloms are subdivided by dorsal and ventral mesenteries. In this genus the tail coelom is further subdivided by lateral mesenteries. In Sagitta, the coelom lacks the peritoneal lining.

The coelomic fluid is colourless. It lacks definite cells, but minute floating granules are present.

Digestive system

The digestive tract of Sagitta is a straight tube running between the mouth and anus. As described earlier, the mouth is situated at the ventral side of the head and is provided with grasping teeth acting as jaws. The mouth leads into a muscular *pharynx* which becomes dilated posteriorly as *pharyngeal bulb*. The pharynx is lined by granular secretory cells, but in the pharyngeal bulb the cells have compound granules. True stomach is absent. The pharynx passes down to the straight *intestine*. The intestine, just near its commencement, gives off a pair of *diverticula* on the lateral sides. The intestine terminates into the anus situated at the junction of trunk and tail.

Circulatory, respiratory and excretory systems

In Sagitta, there is no trace of three systems, such as, circulatory, respiratory and excretory systems. With all possibilities, the coelomic fluid plays the physiological role of circulation, respiration and excretion.

Nervous system

The nervous system is fairly developed in Sagitta. It consists of a large *cerebral ganglion* or *brain* on the dorsal side of the pharynx and an elongated *subenteric* or *ventral ganglion* beneath the pharynx. Both the ganglia are connected by *circumenteric connectives*. Two pairs of ganglia—one pair of *vestibular ganglia* and another pair of *pharyngeal ganglia* are connected with the brain. From these ganglia nerves spread out to the various parts of the body.

Sense organs

The organs of special senses are present in Sagitta. The sense organs are: (1) *Sensory bristles*. Longitudinal rows of elongated cells with delicate bristles are regarded as tactile organs. (2) *Ciliated loop*. The *ciliated loop*, as described earlier, with all probabilities, acts as chemoreceptor. (3) *Eyes*. Two eyes are present on the dorsal side of the head. Each eye has five closely applied pigment-cup ocelli.

Reproductive system

Like all other Chaetognaths, Sagitta is bisexual. The *ovaries* and *testes* are paired structures. The ovaries are elongated solid bodies situated in the posterior part of the trunk coelom just in front of the trunk-tail coelomic septum and remain attached with the body wall by mesentery. The *oviduct* is very peculiar in having two tubes

—one tube within another. The inner tube has a syncytial wall and it becomes expanded posteriorly to form *seminal receptacle*. The wall of the oviduct proper, i.e. the outer tube is composed of columnar or cuboidal epithelium. The transportation of the egg from the ovary to the oviduct is very peculiar in Sagitta. At the time of maturity of each egg, two cells from the inner tube of the oviduct move and make an *attachment stalk* for the egg. This attachment stalk becomes subsequently hollow to form a narrow canal through which spermatozoa from the seminal receptacle migrate and fertilize the egg.

The *testes* are located in the tail coelom just posterior to the trunk-tail coelomic partition. At the time of sexual maturity, clusters of *spermatogonia* become detached from the testes into the tail coelom where spermatogenesis occurs. The *vas deferens* has a funnel-like coelomic opening called *coelomostome* and the other end dilates to form *vesicula seminalis*. There is no permanent male gonopore, the filiform sperms escape by rupturing the body wall.

Development

Fertilization is internal. In Sagitta, self-fertilization is the rule, but in other Chaetognaths cross-fertilization occurs. The egg contains little quantity of yolk material. The egg undergoes holoblastic or equal cleavage and a coeloblastula is formed. The coeloblastula eventually gastrulates in embolic fashion. The most significant event in the development of Sagitta is the precocious differentiation of primordial germ cells. The embryo becomes elongated and hatches out of the egg shell as a miniature animal. Thus, in Sagitta the development is direct.

HISTORY

Slabber, in the year 1769, was the first worker to record *Sagitta* and he placed it in the order Intestina under phylum *Vermis*. Since then extensive works on various aspects of Sagitta have been performed by a host of workers. It was Leuckart (1854) who was the pioneer to create a separate group, *Chaetognathi* for Sagitta. Both Leuckart and Gegenbaur (1854) placed Chaetognathi between Nematodes and Annelids. Butschli (1910) placed the Chaetognathi along with Ectoprocta, Phoronida, Brachiopoda and others under the subphylum Oligomera. This subphylum was in turn placed under phylum Vermis. Up to the present day the relationships of Chaetognathi remain controversial. So a separate phylum is created to accommodate the different Chaetognaths. The original spelling of the phylum 'Chaetognathi' by Leuckart is slightly modified as phylum Chaetognatha.

Besides those authors, the contributions made by Kowalevsky (1870), Hertwig (1880), Grassi (1883), Gourret (1884), Doncaster (1902), Gunther (1819), Burfield (1927), etc. are of considered valuable.

AFFINITIES

The Chaetognaths were first discovered by Slabber in 1769. But uptil now the systematic position of Chaetognaths remains problematic. Because of structural resemblances with different invertebrates, they were included under Mollusca, Annelida, Nemathelminthes, Arthropoda and some enterocoelous forms. The relationship of Chaetognaths with Molluscs, Annelida and Arthropods becomes extremely difficult to establish. All the similarities are superficial in nature and have no specific phylogenetic significance.

Relationship with Nematodes

The anatomical organisation of the Chaetognaths exhibits structural similarities with pseudocoelomate forms, specially the Nematodes. Some such similar features are mentioned below: (1) The fins of Chaetognaths can be compared with the *alae* of nematodes. (2) Presence of ganglionated circumenteric nerve ring in both. (3) The muscular pharyngeal bulb of Chaetognaths resembles closely to that of Nematodes. (4) Restriction of the body wall musculature into four longitudinal muscle bands in Chaetognaths resemble that of Nematodes. (5) Similar histological construction of muscles in both. (6) The adhesive bristles in the head of some marine Nematodes correspond to the grasping spines of Chaetognaths.

Despite these similarities in adult condition, the embryological stages offer wide diversities, particularly in the development of coelom. The enterocoelous development of coelom in Chaetognaths stands as a strong barrier to establish the

nematode affinity, although it has been advocated by Schneider (1866) and Metschnikov (1867).

Relationship with Brachiopoda

Many authors, specially Lameere (1931) tried to relate Chaetognaths with the Brachiopods. Lameere advances the following arguments to support his contention:

(1) The grasping spines of Chaetognaths are comparable to the lophophore of Brachiopoda. (2) Existence of few similarities in embryonic development. But the above points are not sufficiently convincing to establish such a relationship. The point of grasping spines seems rather superficial in nature. The development of coelom also offers points of difference. In Brachiopoda the coelom develops in four different parts of the body. So none of these two points are sufficient enough to establish relationship with Brachiopoda.

Relationship with Echinodermata and Hemichordata

The enterocoelous formation of coelom in the embryonic stage of Chaetognaths led many zoologists to establish the phylogenetic relationship with the Echinodermata and Hemichordata. But the mode of formation of coelom is different in these groups. In Chaetognaths coelom develops as folds of the archenteron, but in Echinoderms and Hemichordates it develops as outpouching of archenteron. Echinoderms and Hemichordates have free-swimming larval forms, but in Chaetognaths, development is direct, i.e. larval form is absent. The primary division of coelom is also different in them. For this reason the affinities of Chaetognaths with Echinoderms and Hemichordates cannot be established.

Chaetognaths are peculiar in having close structural resemblances with the pseudocoelomates (represented by Nematodes) in the adult stages and with the enterocoelous coelomates—the Echinoderms and Hemichordates in the embryonic development. Such dual affinities, become difficult to correlate the Chaetognaths with any invertebrate group. Chaetognaths are regarded as primitive 'protocoelomates' and as a blind side branch from the hypothetical ancestral protocoelomate which gave origin to the surviving Bilateria, as represented today by Ctenophores. Because of peculiar anatomical organisation, Chaetognaths constitute an isolated group and occupy an independent status as phylum. Chaetognaths are more related to the enterocoelous forms than any other existing groups in having enterocoelous development of coelom. The modern inclination is to accept the view of MacBride (1914) that the Chaetognaths diverged from the ancestral form, which gave rise to all the modern Bilateria.

PHYLUM POGONOPHORA

The Pogonophora (Gr. *Pagon*—beard) is a very recently established group of animals. The members of this phylum are commonly called 'beard-worms'. It is a very small group and is constituted of nine genera and about twenty-two species. All of them have similar structural construction and a typical representative, *Lamellisabella*, has been described here to get an idea of the group.

EXAMPLE OF THE PHYLUM POGONOPHORA —*LAMELLISABELLA*

Habit and Habitat

Like all other Pogonophores, *Lamellisabella* is exclusively marine and benthonic creature. They are sedentary, tubicolous and free-living animals. The exact mode of nutrition is not known and the digestive tract is wanting.

External structures

Lamellisabella has an elongated slender worm-like cylindrical body ranging from 50–350 mm in length and 0·5 to 2·5 mm in diameter. This animal has a crown of tentacles and it bears a superficial resemblance with an Annelid, *Sabella*. Such resemblance has given rise to the name for the genus *Lamellisabella*. Each worm lives in a chitinous tube formed by its own secretion. The tube is composed of linearly arranged funnel-like pieces (Fig. 19.7A). The tubes are closely fitted separate units and have erect position.

The body is differentiated into two regions—*protomesosome* and *metasome*. The protomesosome is formed by the fusion of protosome and mesosome. The mesosome and metasome are internally separated by a septum. The anterior end of the protomesosome bears circlet of *tentacles* varying from 18 to 31 in number (Fig. 19.7B).

The tentacles are fused at the basal ends so as to form a sort of cylinder. Formation of this cylinder is a characteristic feature of this genus. The tentacles are hollow and are provided with *pinnules*. The pinnules of the tentacles form a food-catching net in the cylinder. The metasome is long and slender and is provided with rows of adhesive papillae for anchorage in the tube. The papillae are provided with minute hard horseshoe-shaped structures. Two oblique adjacent ridges called *belts* divide the trunk into preannular and postannular regions.

Body wall

The body wall comprises of an *epidermis*. The epidermis is lined by *cuticle* on the outer side while a *muscular layer* is present on the inner side. The epidermis proper is composed of columnar and gland cells. The muscular layer is differentiated into a thin circular muscle layer and a thick longitudinal muscle layer.

Coelom

The coelom is not lined by peritoneum. The coelom forms paired compartments in protomesosome and metasome.

Digestive system

The absence of alimentary system has raised doubt about the mechanism of nutrition. The cylindrical space formed by the fusion of basal ends of the tentacles together with the pinnules form a food-catching net which play the main role in nutrition. It is supposed that the ciliary tracts in the pinnules produce water current which carries micro-organisms. These micro-organisms are entangled in the food-catching net. The digestion and absorption of food also occur within the net. Thus it exhibits a peculiar instance where the food is digested outside the alimentary canal.

Circulatory system

The circulatory system is comparatively well-formed and is of closed type. It consists of one *mid-dorsal*, one *mid-ventral* and two pairs of *lateral vessels* in the trunk region. The mid-ventral vessel in protosome becomes enlarged into a muscular *heart*. The pericardial sac is absent in this genus. The blood, which does not contain any cell, circulates posteriorly through dorsal vessel and anteriorly through ventral vessel. Each tentacle is provided with one *afferent* and one *efferent vessel*. These vessels form a loop in the pinnules.

Respiratory system

No definite respiratory organ is present in Lamellisabella. The tentacles serve as the respiratory organs. The body of the worm is protruded anteriorly from the tube for the purpose of gaseous exchange.

Excretory system

The excretory system includes two *nephridia* (modified coelomoducts). The nephridia are situated in the cavity of the protomesosome. Each nephridium is a sacciform structure which opens to the exterior through the nephridiopore (Fig. 19.7C). The nephrostome is absent. The excretory materials are accumulated by the nephrocytes in the coelomic fluid.

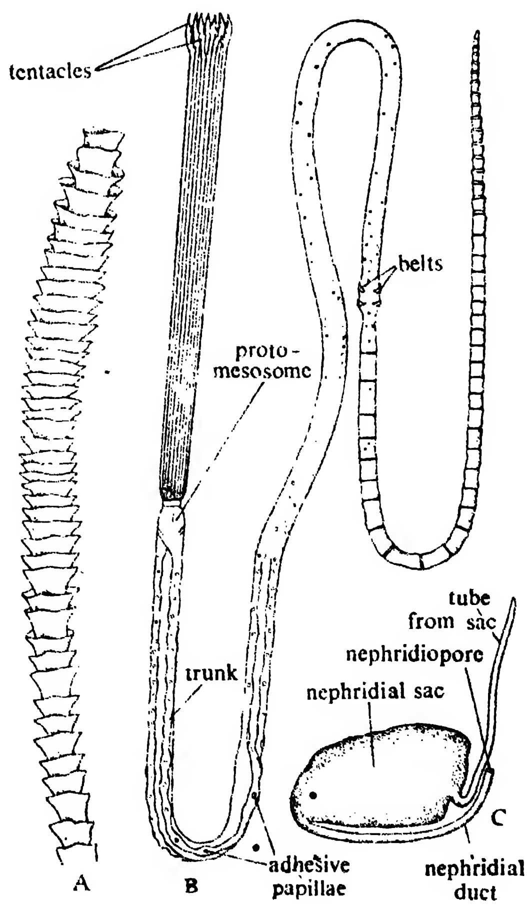


Fig. 19.7. Structural organisation of *Lamellisabella*. A. A tube. B. Ventral view of an entire animal. C. A nephridium.

Nervous system

The nervous system is very primitive in nature and is intra-epidermal in position. It is composed of a ganglionic enlargement in the cephalic lobe of protomesosome. This ganglionic enlargement gives nerve supply to the tentacles and a single mid-dorsal nerve cord emerges posteriorly.

Reproductive system

The sexes are separate. The male and female can be distinguished by the position of the gonopores. The male gonopores are situated behind the protomesosome-metasome septum and the female gonopores are located at the middle region of the metasome. The gonads are elongated paired bodies situated in the metasome.

Development

The eggs are large and yolky. Fertilization is external. The cleavage is holoblastic and results in the formation of a large number of blastomeres. The embryo is bilaterally symmetrical and fusiform in shape. A rudiment of archenteron is formed in the embryonic stage, but it degenerates subsequently. The coelom is enterococlous in origin. The embryo is transformed into an elongated larva which, after a brief free existence, transforms into adult.

CLASSIFICATION

The pogonophores are classified under two orders: Atheeanephria and Thecanephria.

Order *Athecanephria*. The tentacles are free. The protosome and mesosome are distinct. Ventral adhesive papillae are lacking from the posterior part of the trunk. Nephridiopores are laterally placed. Pericardial sacs are present, e.g. *Siboglinum*, *Oligobrachia*, *Birsteinia*.

Order *Theoanephria*, e.g. *Lamellisabella*, *Spirabrachia*, *Heptabrachia*, *Polybrachia*, *Galathealinum*, *Galathea*.

In most of the cases the tentacles are fused at their basal ends. The protosome and mesosome are mostly combined to form the protomesosome. Ventral adhesive papillae are present in the posterior part of the trunk. Nephridiopores are medially placed. Pericardial sacs are absent.

HISTORY

The first species of Pogonophore was collected in Indonesia in the year 1900. Uschakov, a Russian Biologist in the year 1933, collected some specimens from the depth of 3500 metres in Okhotsk sea. Uschakov described the animals and placed them in the family Sabillidae under the phylum Annelida. But Johannson (1939) pointed out the difficulties to place them under Annelida and created a new group *Pogonofora* (correctly spelt now as Pogonophora). Reisinger (1938) and Ulrich (1949) considered Pogonophora as a separate phylum and placed it between Lophophorates and Hemichordates. Ivanov (1955) proposed the name Brachiata for the phylum, but the term Pogonophora has been retained.

AFFINITIES

The systematic status of Pogonophora is still disputed. However, on the basis of some similarities such as (*i*) retention of blastopore, (*ii*) enterocoelous development of coelom and (*iii*) division of coelom into protocoel, mesocoel and metacoel, it has been suggested by many that the pogonophores may be related to other enterocoelous coelomates (Deuterostomia)—the Echinodermata and Chordata. The relationship between Pogonophora and Hemichordates is quite striking.

Relationship between Pogonophora and Hemichordata

The Pogonophora and Hemichordata show many points of resemblances. These are: (1) undivided protocoel with a pair of coelomoducts and external apertures, (2) similar pericardial sac, (3) a septum dividing mesocoel and metacoel, (4) gonad situated in the trunk, (5) intra-epidermal nervous system and (6) absence of no peritoneal lining in the coelom.

But there are many points of dissimilarities between these two groups which make it difficult to draw the affinities between them. They are: (1) lack of adhesive papillae in Hemichordata, (2) absence of gill-slits in Pogonophora, (3) localisation of nervous mass in the protosome in Pogonophora and in mesosome in Hemichordata, (4) position of heart is ventral in Pogonophora and dorsal in Hemichordata, (5) different position of gonopores and (6) lack of homology

between the tentacular apparatus of the two groups.

Pogonophora exhibits close similarities with Hemichordata but because of the differences discussed above it will be difficult to include them under Hemichordata. However, it may be suggested that the similarities between Pogonophores and hemichordates are due to remote phylogenetic connection. From the above discussion, it is convenient to place the pogonophores under a separate and independent phylum—Pogonophora. The phylum forms a distinct metazoan group with peculiar individual characteristics like the absence of alimentary canal.

THE LOPHOPHORATE COELOMATE PHYLA

The Phoronids, Brachipods and Ectoprocts are generally called lophophorate coelomates, as they possess many common features, viz. lophophore, trochophore type of larval form and similar division of coelom. The points of resemblance are so profound that many authors grouped them under one phylum. But closer examination reveals that they have many individual characteristics which are difficult to interprete. In our present discussion, the three groups are dealt under separate phyla.

PHYLUM PHORONIDA

The biological status of Phoronida in the animal kingdom is uncertain. Because of its peculiar anatomical organisation and structural resemblances with many other groups, the phoronids have been the subject matter for various discussions. Some recent authors like Hyman (1959), tried to give Phoronids the status of a separate phylum. The Phoronida has two genera under it. The genera are, *Phoronis* and *Phoronopsis*. There are about 15 species under each genera. Before going to discuss on that particular issue, a typical representative of the phylum, *Phoronis* is described below. This genus has several species and all of them have slender, and vermiform bodies inhabiting in secreted tubes.

EXAMPLE OF THE PHYLUM PHORONIDA—*PHORONIS*

Habit and Habitat

Phoronis is exclusively a marine animal and lives in sandy bottom in shallow seas. In the adult stage, it is sedentary and becomes enclosed by a membranous or leathery tube, within which the animal is capable of being retracted. The tube is formed from the secretion of the animal. Particles of foreign matters, such as, sand grains, sponge spicules, shells adhere to the tubes (Fig. 19.8A). *Phoronis ovalis* has the habit of burrowing in rocks and calcareous shells. It has a wide range of geographical distribution. It is a ciliary-mucious feeder and eats on micro-organisms brought by water current.

External structures

Phoronis has an unsegmented, tubiculous and elongated body. The body is differentiated into an anterior *lophophore* and a posterior *trunk*. The lophophore is horseshoe-shaped with spirally coiled lateral *cornu*. The cornu are supported by mesodermal skeleton. A bunch of slender ciliated *tentacles* is present on the lophophore. In Phoronis, the crown of tentacles is separated by a groove. Both the *mouth* and *anus* are located at the tentacular end. Overhanging the mouth a broad lobe called *upper lip* or *epistome* is present. Two ciliated nephridial tubes open near the anus. The trunk region of the body is narrow, cylindrical and is devoid of appendages. The trunk is of uniform diameter throughout the length except at the posterior end where it becomes enlarged to form the *end bulb* or *ampulla*. The trunk shows faint annulations.

Body wall

The body wall is made up of *cuticle*, *epidermis*, *basement membrane*, *muscular layers* and *coelomic epithelium*. The cuticle is well-developed in the lophophoral region. The epidermis is composed of columnar cells, neurosensory cells and gland cells. The epidermis in the tentacles is ciliated. At the basal part of the epidermis throughout the body, lies the nervous layer. Between the epidermis and the muscular layer there is a basement membrane. The muscular layer is composed of thin outer circular muscle and thick inner longitudinal muscle. The coelomic epithelium is syncytial in nature.

Coelom

The coelom is spacious. The coelom is divided into two major parts by an oblique *diaphragm* which runs across posterior to the tentacular crown. The anterior part

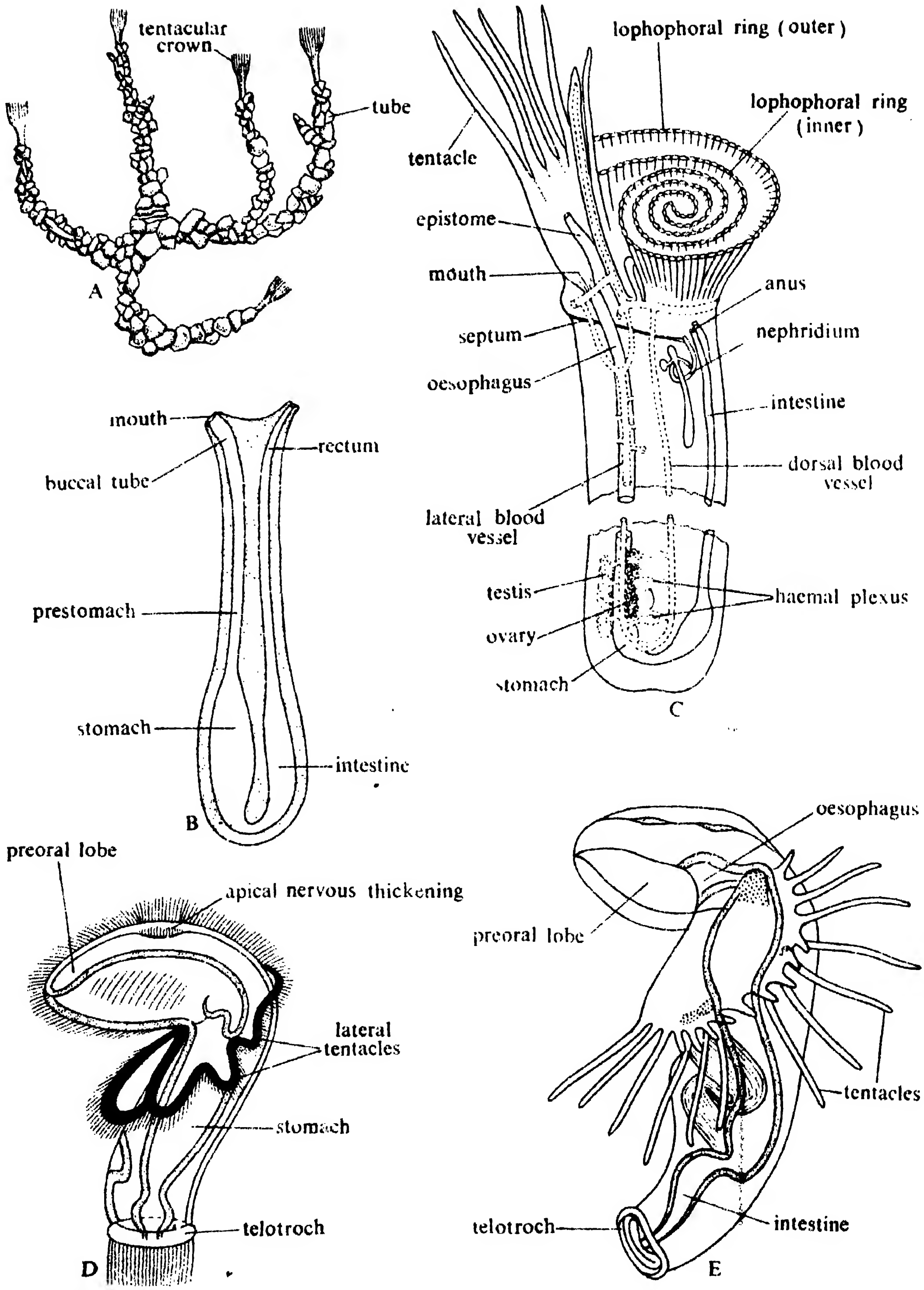


Fig. 19.8. A. Few specimens of *Phoronis* within the tubes. Note that the tubes are coated with stone grains. B. Digestive tract of *Phoronis*. C. Diagrammatic sectional (sagittal) view of *Phoronis*. D. Young Actinotrocha larva. E. Mature Actinotrocha larva.

of the coelom includes the cavities in the tentacular epistome and lophophore. This part of the coelom is devoid of external openings. The posterior trunk coelom (*metacoel*) is quite extensive and occupies the whole length of the trunk. The metacoel, in adult, becomes usually divided into four longitudinal compartments by mesenteries, two dorso-lateral and two ventro-lateral. The posterior trunk coelom is communicated with the exterior through the nephridia.

The coelomic fluid is a colourless albuminous fluid and contains coelomocytes, red blood corpuscles, spindle bodies and pigment cells.

Digestive system

The alimentary canal is a long tube which bends on itself to form a 'U'-like loop and is broadly differentiated into oesophageal, gastric and intestinal regions (Fig. 19.8B). The crescentic mouth receives ciliated grooves from the lophophore. The mouth leads into the *oesophagus*. The wall of the oesophagus is thick and contains internal folds. The oesophagus leads into a long descending tube called *prestomach* or *proventriculus*. This part lacks muscular layer but possesses an internal mid-dorsal ciliated band. The prestomach in the end bulb becomes dilated to form a roundish *stomach*. The stomach has an inner ciliated epithelium in the middle region, but at the two sides the epithelium becomes syncytial. The ascending limb of the alimentary canal is the slender *intestine* which is demarcated from the stomach by a constriction. The intestine passes into the *rectum* and opens to the exterior through the *anus*.

Circulatory system

The blood contains only red blood corpuscles. The blood vessels are closed tubes and are contractile in nature. These blood vessels subserve the functions of heart. There are two main longitudinal blood vessels running along the trunk (Fig. 19.8C). These vessels are: (*a*) Afferent or dorso-median vessel and (*b*) Efferent or ventro-lateral vessel. The blood flows from the posterior to the anterior side through the dorso-median vessel, whereas by the ventro-lateral vessels the blood is carried to the posterior side. The dorso-median vessel in the lophophoral coelom bifurcates to form an afferent ring vessel which gives a vessel to each tentacle. The tentacular vessels unite with the efferent ring vessel which in turn is connected with the ventro-lateral vessel or efferent vessels. Aborally, the dorso-median and ventro-lateral vessels communicate with the haemal plexus of the gut wall.

Excretory system

The excretory system comprises of a pair of nephridia, which is also called metanephridia. Each nephridium is a 'U'-shaped tubular structure and is lined throughout its length by ciliated epithelium. It opens to the exterior through nephridiopore on the side of the anus. The nephridia also act as gonoducts.

Nervous system

The nervous system consists of *nerve fibres* and *nerve cells*, which form a distinct *nervous layer* beneath the epidermis. This nervous layer becomes differentiated into a *nerve ring* at the anterior end of the body, which is regarded as the *preoral nervous field* and it gives nerves to the tentacles. The nerve ring becomes thickened and broadened mid-dorsally. In addition, a *lateral nerve* (a cylindrical giant nerve fibre covered by a sheath) is present. In most of the species lateral nerve is present on the left side, except in a few species where it may also be present on the right side. The lateral nerve innervates the trunk musculature.

In Phoronis, sense organs are represented only by neurosensory cells.

Reproductive system

Phoronis is hermaphrodite. Specialised cells on the inner coelomic wall produce sperms and ova. Fertilization occurs either in the body cavity or in the lophophoral cavity where reproductive cells are brought out through the nephridiopores.

Development

After the completion of fertilization, development occurs in the cavity enclosed by the tentacles. The development is indirect. Cleavage is holoblastic and is slightly unequal. The cleavage results into the formation of coeloblastula. The vegital pole of the coeloblastula becomes flattened and invagination starts in typical embolic fashion. The mesoderm is budded off from the endoderm. The coelomic spaces arise as diverticula from the enteric wall. After

the completion of development, a ciliated larval form is produced. The larva is a free-swimming form and has an oval body. The preoral lobe becomes expanded and bent forward. The alimentary canal is differentiated into oesophagus, stomach and intestine. As the larva develops, the cilia become restricted to certain areas of the body. The fully-developed larva is called *Actinotrocha* larva. It has an elongated form ranging from 1–5 mm. Overhanging the mouth of the larva there is a hood-like hollow *preoral lobe* and a circlet of ciliated tentacles (Fig. 19.8D, E). An *apical plate* with eye spots is present in the preoral lobe of the larva. A pair of excretory organs with solenocytes are present. Another post-oral ciliated ridge is present below the mouth. A girdle of slender tentacles originating from the preoral lobe surrounds the anterior part of the larva. Actinotrocha larva settles down to the bottom and transforms into an adult. This larva bears close resemblance with the Tornaria larva of Balanoglossus.

HISTORY

The phoronids constitute a very important group amongst the lophophorate coelomates. The name of the group as *Phoronida* was first coined by Hatschek in 1888. Another name, *Phoronidea*, proposed by Lang has not been universally accepted. Before the establishment of group, many workers studied the biology of many Phoronids. J. Muller and his student, Wegener in the year 1847 first observed numerous free-swimming animals on the surface of the sea. Both the workers wrongly took them as adult forms and named them as *Actinotrocha branchiata*. But their larval nature was pointed out subsequently by Gagenbaur (1854). Wright (1856) first observed an aggregate of many adult worms inhabiting the tubes and called the animals as *Phoronis*. Kowalevsky (1867) and Metschnikoff (1871), by following the developmental sequences, have established the fact that the Actinotrocha larva metamorphoses into adult Phoronis. This observation led to the fact that the Phoronis is the adult worm and the Actinotrocha is its larval stage.

AFFINITIES

The biological status of the Phoronida in the animal kingdom is a disputed issue. Because of the peculiar anatomical organisation and structural resemblances with other groups, Phoronida has been a controversial subject since its discovery. Amongst all other groups, Brachiopoda and Ectoprocta resemble very closely with the Phoronida. The Phoronida, Brachiopoda and Ectoprocta are collectively called the lophophorate coelomates. On the basis of their similarities, these three groups, were regarded by earlier Zoologists, specially by Milne-Edwards (1843) and T. H. Huxley (1853) as a single phylum *Molluscoidea*. But due to their wide structural divergences and lack of mutual relationships, the scheme has been totally abandoned. Caldwell (1882) also established the relationship between the three groups. Hatschek (1888) placed them in different classes under the phylum *Tentaculata*. Such attempts of combining them under one phylum seems to be inappropriate. Hyman (1959) suggested an alternate name, *Lophophorata* for these groups because of the presence of lophophore. In spite of all attempts to include them under one group, it is improper to draw any definite affinity between them, because there are many structural differences. This aspect will be clear from the following discussion.

Relationship with Brachiopoda

The Phoronida exhibits close resemblances with Brachiopoda. The similarities are: (1) Presence of similarly constructed horseshoe-shaped lophophore. (2) Presence of an epistome. (3) Presence of a U-shaped alimentary canal. (4) A coelomic septum is present separating the mesosome and metasome, although poorly developed in Brachiopoda, except in *Crania* where the septum is complete. (5) Presence of sub-epidermal nervous plexus which forms a nerve centre in the mesocoel. (5) A pair of metanephridia are present. These are the coelomoducts of metacoel and also act as gonoducts. (7) The mouth originates directly from the blastopore in both. (8) In both the cases the dorsal surface between mouth and anus is extraordinarily shortened. The Phoronida and Brachiopoda, though possess many similar features, have many structural differences which do not support the supposed affinities. The main differences are: (1) The nerve centre is supra-enteric in Phoronida but subenteric in Brachiopoda. (2) In Phoronida, two

sets of tentacles are present, one is the larval set and the other is the definitive set. But in Brachiopoda, larval tentacles are lacking. (3) The brachiopod shell cannot be correlated with the exoskeleton of Phoronida. (4) The chitinous setae in larval and adult Brachiopoda have no counterparts in Phoronida. (5) The circulatory system in Phoronida is more developed than in Brachiopoda. In Phoronids the blood vascular system is composed of closed blood vessels, whereas in Brachiopods it is of open type. (6) In Phoronida, the cleavage pattern is spiral, but in Brachiopoda cleavage is not spiral.

Relationship with Ectoprocta

The relationship between Phoronida and Ectoprocta has also been emphasised by Caldwell (1882). The idea was based on the existence of the following similar features: (1) The nerve centre is situated in the mesocoel and is supraenteric in both. (2) The lophophore is horseshoe-shaped. (3) Epistome is present. (4) Alimentary canal is bent to form a U-shaped tube. (5) The disposition of coelom is similar and a septum separates the mesocoel from the metacoel. But a detailed study of the two groups shows many structural dissimilarities. They differ widely from both anatomical and embryological point of view. The following points stand as barriers to draw the relationship between them. They are: (1) The origin of coelom is different. In Phoronida, the coelom is endomesodermal in origin, while in Ectoprocta it is ectomesodermal. (2) The region between the mouth and anus is dorsal in Phoronida but in Ectoprocta it is ventral. (3) Circulatory system and nephridia are absent in Ectoprocta but in Phoronida both the systems are present and well-formed. (4) The developmental sequences vary quite greatly.

Because of the presence of wide structural differences, the relationship between Ectoprocta and Phoronida cannot be justified. Of the three lophophorate coelomates, the Phoronids are nearer to the lophophorate ancestor because they resemble each other by the following points: (1) Muscular vermiform body with cresentic lophophore. (2) Existence of a septum between an anterior lophophore bearing part and a posterior trunk. (3) Circulatory system is of closed type with dorsal and ventral vessels. (4) Trochophore type of larva has protonephridia.

Relationship with Annelida

The relationship between Annelida and Phoronida is mainly based on the larval similarities. Because of their resemblances, the Actinotrocha is regarded by many authors to be a modified Trochophore larva. The points of resemblances are: (1) The tentaculate lophophore of Phoronida corresponds to the tentacular crown of *Sipunculus*. (2) In both Annelida and Phoronida the mature germ cells pass out through the nephridia. (3) The Actinotrocha larva and the Trochophore larva possess many common features: (*a*) Both of them are free-swimming ciliated pelagic forms with distinct preoral lobe. (*b*) The girdle of larval tentacles develop from the ciliary band. The cilia bordering the preoral lobe of Actinotrocha represent the metatroch and prototroch of Trochophore respectively. The disposition of the telotroch is similar in both. (*c*) A thickening of the ectoderm of the preoral lobe in Actinotrocha represents (sometimes bearing eyes) the apical plate of Trochophore. (*d*) A pair of solenocytic nephridia are present. (*e*) In both the larval forms the alimentary canal is similarly placed and has similar divisions. But closer examination reveals that the Annelida and Phoronida are fundamentally different in their organisation. The most important point lies in the development of mesoderm. In Actinotrocha mesoderm is endomesodermal. The body of Phoronida is unsegmented, but in Annelida segmentation is the main criterion in their organisation. In Trochophore mesoderm is arranged in teloblastic bands. The relationship between Annelida and Phoronida cannot be justified by critical examination, but the larval resemblances are quite striking. These larval similarities may be due to their adaptive convergence.

Relationship with Hemichordata

Many workers, specially A. Masterman (1897), tried to establish the relationship between Phoronida and Hemichordata. The relationship is primarily based on the similarities in the larval forms, between the Actinotrocha larva and the Tornaria larva of Hemichordata. The similarities are: (1) The body division of Hemichordata (Proboscis, Collar and

Trunk) corresponds to the body division of the Phoronida (Epistome, Mesosome and Trunk or Metasome). (2) A pair of glandular pockets opening into the proximal end of the stomach of Phoronida are supposed by Masterman to be the paired notochord. (3) Presence of a septum between the middle and posterior sectors of the body in both the forms. (4) The position of the tentaculate lophophore is similar to the tentaculated arms of *Cephalodiscus*, a member of Hemichordata. (5) Presence of superficial similarities in the disposition of larval coelom. But a thorough analysis reveals many differences. The differences are: (1) The three divisions of the body of Phoronida are not justified by embryological data. Actually, Phoronida has two divisions in the body. The epistome of Phoronida is not a body region and does not contain coelom like that of proboscis of Hemichordata. (2) The mesocoel of Phoronida communicates to the exterior through metanephridia which are absent in Hemichordata. (3) The coelom in Actinotrocha is divided into three compartments, but in Trochophore, the collar coelom and trunk coelom are paired. (4) The notochordal nature of the glandular pockets in Phoronida is difficult to interprete. From the above points it is quite apparent that most of the arguments forwarded by Masterman to establish the relationship between the Phoronida and Hemichordata are not corroborated by embryological facts. Most of the points of resemblances are based on assumption save for the septum between the middle and posterior sectors of the body and the similarity between the tentaculate lophophore and the tentacular crown in *Cephalodiscus*. Because of the similarities it may be suggested that the two groups inherited these characters from a remote common ancestor.

Even after reviewing the relationship of Phoronida with other groups the biological status of Phoronida remains still unsolved. The affinities between Brachiopoda, Ectoprocta and Phoronida cannot be denied, as they have many similar structures. But the idea to include them within the phylum Molluscoidea or Tentaculata or Lophophora cannot be justified. Of the lophophorate coelomates, Phoronida is nearer to the lophophorate ancestor because of the reasons stated before. Another significant point is the nature of the Actinotrocha larva of Phoronida. This larval form is regarded as the modified form of Protostomous phyla by a host of workers. The larval similarities are so close that the above relationship has solid basis to reject all pleas. The Phoronida also presents many similar features with the Deuterostomous phyla. Because of its dualistic affinities with the Protostomous phyla in one hand and the Deuterostomous phyla on the other, it is considered that the Phoronida forms a sort of connecting link between the Protostomous phyla (Platyhelminthes, Nemalthelminthes, Sipunculida, Echiuroidea, Annelida, Mollusca, etc.) and the Deuterostomous phyla (Echinodermata, Pogonophora, Chordata, etc.). In our present discussion, the phoronids are given the status of a separate phylum which is characterised by some specific features.

PHYLUM BRACHIOPODA

The brachiopods or 'lamp-shells' represent a peculiar group of bilaterally symmetrical coelomates. They are placed in the phylum Brachiopoda which is allied to Phoronida and Ectoprocta. The name of the phylum came from two words, *brachion* =arm and *pados*=foot, which actually refers to the folded tentaculated arms of lophophore of Brachiopoda. The phylum Brachiopoda has a few peculiar characteristics. They are: (1) Solitary and bilaterally symmetrical coelomate animals with bivalved shell. (2) Sedentary forms which are attached to the substratum either directly or through a peduncle. (3) Provided with a tentaculated lophophore. (4) Circulatory system has a contractile dorsal vesicle. (5) One or two pairs of metanephridia are present which also function as gonoducts. In all the brachiopods the structural organisation is more or less similar excepting the nature of articulation of the two shell valves. In our present discussion the biology of a typical genus, *Magellania* has been described.

EXAMPLE OF THE PHYLUM BRACHIOPODA—*MAGELLANIA*

Magellania (*Waldheimia*) is a highly specialised genus of the family Terebratellidae under the class Articulata. This genus contains several species distributed in the various parts of the world.

Habit and Habitat

Magellania, like all other brachiopods, is a marine and benthonic animal. Brachiopods are present in all the seas and at all depths extending from the intertidal zones to the depth of 5000 m. The genus *Magellania* includes several species which are widely distributed but are quite abundant in the coast of New Zealand. They remain attached by peduncle to rocky bottoms (Fig. 19.9A). They are ciliary-mucus-feeders and lophophore is the efficient food-driving apparatus. The food includes minute organisms, specially the diatoms.

External structures

The body of Magellania is provided with shell which is divided into a dorsal and a ventral valve. The valves are more or less oval in shape and are unequal in size. The ventral valve is larger and projects over the dorsal valve and forms a short *beak*. A *peduncle* or *pedicel* emerges through an oval foramen present in the beak and the animal fixes itself on the substratum by the peduncle. The two valves are bilaterally symmetrical and are hinged posteriorly by tooth and socket arrangement.

The dorsal valve has a strong *cardinal process*. *Lines of growth* are represented by concentric rings on the surface of the shell valves. The shell has a thin external covering called *periostracum*. This layer is produced by organic materials which are probably chitinous in nature. The main inorganic component is the calcium carbonate.

The body proper is situated inside the posterior end of the shell (Fig. 19.9B). The mantle cavity is largely occupied by a large *lophophore*. The lophophore is a prolongation of the anterior body wall. It is large in size and occupies the greater part of the *mantle cavity*. The dorsal shell valve is related to the lophophore. The lophophore is supported by internal skeleton called *brachidium* or *brachial support*. The brachidium consists of a pair of prongs called *crura*. Inside the lophophore the crura are continued forward as a calcareous ribbon which forms a loop. This long curved loop is present on the dorsal valve. The loop is not attached with the dorsal valve. The calcareous support of the lophophore develops from the inner lamina of the dorsal mantle lobe. The lophophore is provided with long ciliated *tentacles* which help in food capture. The lophophore shows extreme variations in different brachiopods. The type present in Magellania is called *plectophous* type, i.e. a median coiled arm develops between the two simple lateral arms.

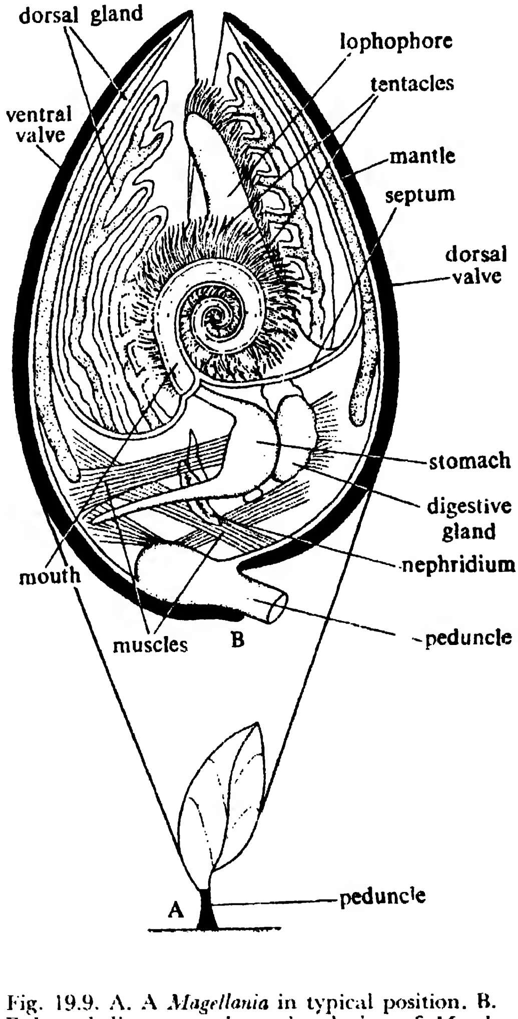


Fig. 19.9. A. A *Magellania* in typical position. B. Enlarged diagrammatic sectional view of *Magellania* to show the internal organs.

Body wall and Masculature

The body is covered by a single-layered epidermis on the outerside. The epidermal cells are cuboidal or columnar in shape. Interspersed with the epidermal cells there are gland cells. Beneath the epidermis there is the median connective tissue layer which shows besides the fibres, a cartilaginous consistency in many parts. The

inner lining comprises of a thin ciliated *peritoneum*. The body wall has muscle layer in the inner side of the peritoneum, in the mantle lobes and the lophophore.

Three sets of specialised muscles are present. The *adductor* or *occlusor* muscle and the *divaricator* or *diductor* muscle that help to open the valves and the *peduncular* muscles operate the peduncle.

Coelom

The coelom is spacious and the space is divided into three compartments—*protocoel*, *mesocoel* and *metacoel*. These compartments are partially separated from each other. The mesocoel gives large arm canals to the lophophore. The coelom contains mesenteries and muscles. The metacoel constitutes the main body cavity containing major part of the alimentary canal, shell muscles, nephridia, gonads, etc. It is also continued into the mantle lobes as *mantle canals*. This coelom communicates with the exterior through a pair of metanephridia.

The coelom is filled with a fluid containing several types of free coelomocytes.

Digestive system

The *mouth* is a transverse slit-like aperture situated at the middle of the lophophore which leads into a U-shaped alimentary canal. The mouth leads into an *oesophagus* which opens into a large *stomach*. There is a large *digestive gland* or *liver* which opens into the stomach. The liver occupies most of the inner space and is composed of numerous spherical acini. The product of the liver is poured into the stomach by one to three large ducts. The stomach passes into an *intestine* which ends blindly, i.e. the anus is wanting.

Respiratory system

There is no specialised respiratory organ in Magellina, but the lophophore, in addition to food-catching function, plays the respiratory role. The water current plays double functions of feeding and of drawing in and expelling out respiratory gases. The coelomic fluid present in the tentacular canals, helps in gaseous exchange.

Circulatory system

The circulatory system is of open type. The blood channels have no definite wall. These are mere spaces inside the mesenteries. The blood is a colourless and cell free fluid. A globular contractile sac, called 'heart' is present. It is attached to the posterior region of the stomach. The blood channels, arising from the heart supply the various parts of the body.

Excretory system

The excretory system consists of one pair of *metanephridia* situated in the metacoel. Each metanephridium is a tubular structure, one end of which opens into the coelom by a wide funnel-shaped *nephrostome* while the other end extends anteriorly and opens into the mantle cavity through *nephridiopore*, situated one on each side of the mouth. In addition to the excretory function, the metanephridia also acts as gonoducts.

Nervous system and Sense organs

The nervous system comprises of a *circumenteric nerve ring* with a large *subenteric ganglion* and a smaller *supraenteric ganglion*. The circumenteric nerve ring supplies nerves to the arms and tentacles. The subenteric ganglion gives out several lateral nerves supplying the dorsal mantle lobe and a pair of thick trunk nerves to the posterior side which innervate the ventral mantle lobes, the adductor muscles and finally proceed to the peduncle as peduncular nerve.

Special organs of sense are lacking in Magellania, but in other Brachiopods they are represented by statocysts, eyes and sensory patches.

Reproductive system and Development

The sexes are separate. The gonads are localised modifications of the peritoneum and are four in number. They resemble bunches of grapes and become considerably enlarged during maturity. When the gametes become mature they are discharged into the metacoel from where they are conveyed to the exterior through metanephridia which act as the gonoducts.

Fertilization is external. The cleavage is holoblastic and occurs along the radial plane. A coeloblastula is formed which eventually becomes a gastrula by emboly. Coelom is enterocoelous in this case. Mesoderm differentiates as a single sac which becomes separated off from the posterior end of the archenteron by a

developing partition. After subsequent developmental stages, a free-swimming ciliated larva emerges out which resembles closely the annelidan trochophore larva. After a short free-swimming phase the larva fixes itself with the substratum by the peduncular region and metamorphoses into an adult.

CLASSIFICATION

The brachiopods are noted for their abundance in the geological strata of the earth. Cooper has calculated about 30,000 species of fossil brachiopods. At present, the brachiopods are represented by 68 genera having about 260 existing species. The scheme of classification described here concerns only the existing brachiopods. The phylum Brachiopoda is classified into two classes—Ecardines or Inarticulata and Testicardines or Articulata.

Class **Ecardines** or **Inarticulata**

The representatives of this class have (*i*) shell valves which are not united by hinge but by muscles only; (*ii*) no shelly loop supporting the lophophore and (*iii*) anus is present. The class contains two orders: *Atremata* and *Neotremata*.

Order *Atremata*

The shell is mostly composed of calcium phosphate. The foramen, through which the pedicle passes out, is formed by both the shell valves. Examples: *Lingula*, *Glottidia*.

Order *Neotremata*

The shell may be composed of calcium carbonate. The pedicle foramen is usually confined to the ventral shell valve alone. The representatives are: *Crania*, *Craniscus*, *Pelagodiscus*, *Discina*, *Discinisca*.

Class **Testicardines** or **Articulata**

The members have (*i*) shell valves united by hinge apparatus, (*ii*) shelly loop is present supporting the lophophore and (*iii*) intestine terminates blindly, i.e. the anus is absent. The examples are: *Megellania*, *Lacazella*, *Thecidellina*, *Rhynchonella*, *Terebratulina*, *Chlidonophora*, *Dyscolia*.

HISTORY

Starting from late sixteenth century the study of brachiopods has a long history behind. They were, for a longtime, regarded as molluscs because of the presence of characteristic bivalve shell. Linnaeus in 1758 gave the name *Anomia* to the brachiopods and placed them under *Vermis*. By studying the anatomy of *Lingula*, *Terebratula* and *Orbicula*, Cuvier (1797–1802) placed them under the group *Acephal* under Mollusca. The credit of coining the name of the group as *Brachiopoda* goes to Dumeril (1806) who placed it as a separate order under Mollusca. Steenstrup (1847–49) tried to establish the affinity of the brachiopods with the annelids. Since then the workers on this line were divided into two distinct schools—one supporting the molluscan affinity and the others inclined to support the annelidan affinity. T. H. Huxley (1869) discarded the molluscan affinities of brachiopods and placed them as one of the three classes under Molluscoidea, the other two classes being Tunicata and Bryozoa. Caldwell (1882) suggested the close relationship between Phoronida, Brachiopoda, Bryozoa and Sipunculida. The brachiopods, phoronids and bryozoans were grouped under *Tentaculata* by Hatschek (1888) and under *Lophophorata* by Schneider (1902). Because of the controversies regarding the systematic position, the brachiopods have been given the status of a separate phylum called Brachiopoda.

AFFINITIES

As already discussed in the biology of Phoronida, the brachiopods constitute a distinct group of lophophorate coelomates. The Brachiopoda, Phoronida and Ectoprocta possess many similar features, viz. presence of lophophore, septum between mesocoel and metacoel, presence of epistome representing the anterior section (protosome) of the body, chitinous secretion, U-shaped alimentary canal and trochophore like larva. In spite of these common features, the Phoronida, Brachiopoda and Ectoprocta possess many striking individual characteristics which demand serious consideration. Because of that, all the three groups have been given the status of separate phyla.

Relationship with Phoronida. The Brachiopoda and Phoronida have many similar structures, such as, (1) similar lophophore; (2) epistome representing the anterior segment of the body; (3) U-shaped alimentary tube; (4) presence of septum

separating the mesocoel and metacoel; (5) presence of subepidermal nerve plexus; (6) a pair of metanephridia in the metacoel acting also as gonoducts; (7) derivation of mouth directly from the blastopore; (8) the dorsal surface between the mouth and anus becomes greatly shortened. In spite of the similarities, these two groups have many structural differences. The differences are: (1) the nerve centre is supraenteric in Phoronida but in Brachiopoda it is subenteric. (2) Two sets (larval and definite) of tentacles, are present in Phoronida, but in Brachiopoda the larval set is wanting. (3) The shell of Brachiopoda cannot be correlated with exoskeleton of Phoronida. (4) The chitinous setae in Brachiopoda have no counterparts in Phoronida. (5) Circulatory system is of open type in Brachiopoda but in Phoronida it is closed type. (6) The cleavage pattern is spiral in Phoronida, but in Brachiopoda it is not so. Because of such differences the two groups are placed under separate phyla. The similar features are due to remote connection with the ancestral stock.

Relationship with Ectoprocta. The Brachiopoda is related to Ectoprocta by having many similar features. They are: (1) Both Brachiopoda and Ectoprocta have similar body plan. (2) The bivalve shell of *Cyphonautes larva* of Ectoprocta is comparable to the shell of Brachiopoda. (3) A coelomic septum is present between mesocoel and metacoel. (4) U-shaped alimentary canal. But because of the undermentioned differences, the affinities become difficult to be considered. The common features are due to descend from a common lophophorate ancestor. The main differences are as follows: (1) The nervous centre is mainly supraenteric in Ectoprocta, but in Brachiopoda it is subenteric. (2) The brachiopod shell cannot be compared to the exoskeleton of Ectoprocta. (3) The shell is laterally placed in Ectoprocta, but in Brachiopoda the shell is dorso-ventrally placed. (4) The chitinous setae are present in brachiopods, but in Ectoprocta no such setae are observed. (5) The coelomic septum is poorly developed in most brachiopods. (6) The anus is lacking in some brachiopods.

Considering the relationship between the three lophophorate coelomates, it seems reasonable to assume that the phoronida is a primitive group because they have many features common to the lophophorate ancestor. The Brachiopoda constitutes a very divergent group amongst the lophophorate coelomates. Because of the lack of specific relationship between them, the Brachiopoda, Phoronida and Ectoprocta have been treated as separate phyla. The idea of uniting them under a common phylum is not favoured nowadays.

Relationship with Annelida. The Brachiopoda and Annelida have some structural similarities. These are: (1) The setae in Brachiopoda are comparable with those of Annelida. (2) Presence of metanephridia which also act as gonoducts. (3) The larva resembles a trochophore. The larval segmentation is comparable in both.

The main difficulty lies in the origin of coelom in these two groups. Despite the enterocoelous origin of coelom in Brachiopoda, the relationship cannot be established with certainly as both the groups differ fundamentally. Because of the presence of trochophore-like larval form, Brachiopoda is regarded to be related to protostomous phyla.

Relationship with Mollusca. Presence of bivalved shell and mantle-lobes surrounding the body and presence of trochophore-like larval form led many Zoologists to include the brachiopods within the phylum Mollusca. But a closer examination reveals that the shell valves are laterally placed in mollusca, but in brachiopods the shell comprises of dorsal and ventral valves. Because of lack of convincing evidences the relationship cannot be advocated.

After reviewing the relationship of Brachiopoda with other groups, it becomes necessary to place them under a separate phylum having relationship with protostomous and deuterostomous phyla. As regards the interrelationships between different members of the Brachiopoda, it can be suggested that the articulate brachiopods evolved from inarticulate brachiopods along different lines in their phylogenetic history. The geological records show that the brachiopods originated in pre-cambrian period and the oldest brachiopods were the inarticulates belonging to extinct superfamily Obolacea.

PHYLUM ECTOPROCTA (BRYOZOA)

The members of this phylum are commonly called '*sea-mats*' or '*corallines*'. They are microscopic colonial forms which remain permanently attached on various substrata. They resemble superficially the hydroid coelenterates. The colony (termed as *Zoarium*) is composed of *zooids* which constitute the units of the colony. The whole of the zoarium remains covered by exoskeletal case called *zooecium* which opens to the exterior through an *orifice*. The ectoprocts exhibit slight structural diversities and a typical genus *Bugula* has been described below to offer an idea of the phylum.

EXAMPLE OF THE PHYLUM ECTOPROCTA — *BUGULA*

Habit and Habitat

Bugula flabellata is a marine dichotomously branched colonial ectoproct. It is a benthonic animal and remains fixed on any foreign body by its slender root filaments. The colony of Bugula may reach the height of several inches. It is a ciliary feeder and lives on micro-organisms, specially the diatoms.

External structures

The colony of Bugula consists of a number of units called *zooids*. The colony communicates with the exterior through an orifice which is devoid of *operculum*. The zooids are cylindrical in shape and have a wide crescentic *mouth* at the terminal end (Fig. 19.10). The zooids have chitinous wall. The ventral side of the wall has a very thin *cuticle*. The cuticle together with the underlying body wall constitutes the *frontal membrane*. The other walls become much thickened. The living parts of the zooids remain immovably attached to the inner side of the zoecia. The living parts consists of two portions, an anterior protrusible and movable part called *introvert* and the posterior *trunk* which is attached inside to the innerside of the zooecium. The introvert bears a *lophophore* having 14 long filiform tentacles. The tentacles are hollow and contain coelomic cavities. The zooids exhibit polymorphism. The colony has some peculiar pedunculate appendages called *avicularia* (plural of avicularium), resembling closely the miniature head of birds. These are defensive organs.

Body wall

The body wall consists of an outer chitinous zooecium, an underlying epidermis and an inner peritoneal layer. Muscle layer is absent in this genus.

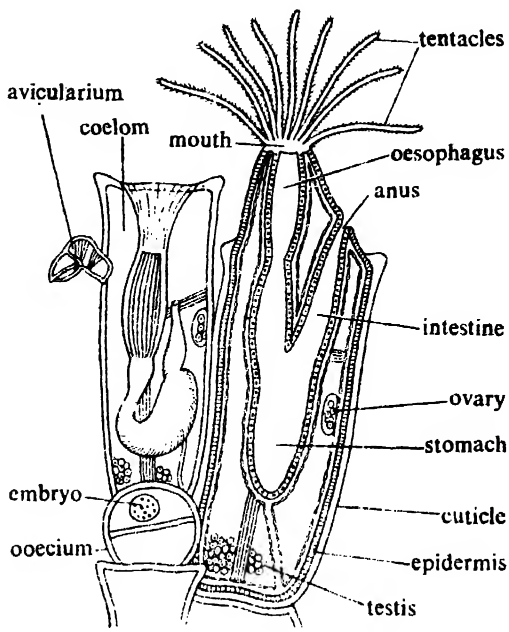


Fig. 19.10. Structures of *Bugula*. Two zooids are shown in a longitudinal section.

Coelom

The coelom is quite extensive and is incompletely divided into two parts by an incomplete septum. The anterior coelom is small and called *ring coelom*. The ring coelom is situated at the base of the lophophore and extends to the tentacles. The *trunk coelom* is large and occupies the space between the body wall and the alimentary canal. The trunk coelom is traversed by 20–40 pairs of muscle fibres which are regarded as the displaced muscles of the body wall. The coelom also contains *funicular cords* which suspend the alimentary canal.

Digestive system

The alimentary canal is a U-shaped tube. The *mouth* is situated at the centre of the lophophore. The mouth leads into a spacious *pharynx* which passes into the *oesophagus*. The pharynx has an internal ciliated lining. The inner lining of the oesophagus is non-ciliated. The oesophagus

leads into *stomach* from where projects a conical *caecum*. The caecum is attached with the body wall by *funiculus*. The intestine terminates in a round *anus* situated near the mouth.

Circulatory system

There is no blood vessel in ectoprocts and the circulatory system is wanting.

Excretory system

Definite excretory organs are lacking in ectoprocts. By introducing vital dyes, it is observed that the coelomocytes, funicular tissues, tentacles and caecum of the alimentary canal help in eliminating the waste products.

Nervous system

The nervous system comprises of a nerve centre in the form of a small *ganglion* situated in the ring coelom. Nerves are given to the various parts of the body from this ganglion. The ganglion is continuous with a *nerve ring* surrounding the pharynx. The nerve ring gives two ganglionated motor and sensory nerve fibres to each tentacle. In this genus, the *tentacular nerves* form an anastomosis with the nerve ring. Special sense organs are absent.

Reproductive system

Asexual reproduction by budding is occasionally found in Bugula. But sexual reproduction is a most common occurrence. It is hermaphrodite. Gonoducts are absent. The *ovary* is an aggregation of *ovocytes* and remains enveloped by a thin peritoneal wall. The *testis* is located at the proximal end of the body and it may be divided into three or four bunches. It exhibits different stages of spermatogenesis. Development takes place in brood chamber which is produced as an outgrowth of the zooecium called *ovicell* or *oecium*.

Development

Self-fertilization has been observed in Bugula. The fertilized egg undergoes holoblastic cleavage and the cleavage plane is of radial type. The coeloblastula is formed which eventually transforms into a gastrula by the process of delamination. During the process of production of 64–128 blastomeres, 4 elongated cells become cut off and enter into the blastocoel. These are actually endomesodermal cells which give endoderm and mesenchyme.

The larva is called *Cyphonautes*. The cyphonautes larva in Bugula shows few specialised features, viz. shape is oval, absence of shell, absence of alimentary canal, delimitation of the apical organ by a circular groove.

CLASSIFICATION

The phylum Ectoprocta is divided into two classes. The classes are: (1) Gymnolaemata or Stelmatophoda and (2) Phylactolaemata or Lophophoda.

Class **Gymnolaemata**

The members of this class are characterised by having a circular lophophore and the absence of epistome. The musculature in the body wall is absent. This class includes five orders.

Order *Ctenostamata*

Zoecia are membranous. Ovicells and avicularia are absent. Examples: *Nolella, Victorella, Clavopora, Paludicella*.

Order *Cheilostomata*

Box-like zoecia which are chitinous or calcareous. Ovicells and avicularia are present. Examples: *Labiostomella, Callopora, Bugula*.

Order *Cyclostomata* or *Stenostomata*

Tubular zoecia which are calcareous in nature. The avicularia and operculum are absent. The representatives are *Tubulipora, Stomatopora, Diplosolen, Berenicea*.

Order *Trepostomata*

This order includes the fossil forms where the zoecia are elongated, tubular and traversed by horizontal partitions. They are colonial forms with massive bodies. The examples are *Heteropora, Batostoma*.

Order *Cryptostomata*

This is also an extinct order of the class Gymnolaemata where the zoecia remain hidden at the bottom of the vestibule. Examples: *Rhombopora, Fenestella*.

Class **Phylactolaemata** or **Lophophoda**

This class includes exclusively the freshwater forms which are provided with horseshoe-shaped lophophore. Epistome and body musculature are present. The members of the class are *Fredericella*, *Pectinatella*, *Lophopus*, *Cristatella*, *Plumatella*, *Stolella*.

Recently D. L. Pawson, J. S. Ryland and W. D. Williams have divided the phylum Ectoprocta (Bryozoa or Polyzoa) into three classes. The classes are: I. Stenolaemata, II. Gymnolaemata and III. Phylactolaemata.

HISTORY

Since early days, ectoprocts were grouped with sessile colonial coelenterates as polyps under Zoophyta. Imperato (1599) and Peyssonel (1753) established the animal nature of the zoophytes. Blainville (1820), Grant (1827) and Edwards (1828) noticed two apertures of the alimentary canal in ectoprocts and treated them as a more highly organised group than the true coelenterate polyps which possess only one opening. The ectoprocts were given the name Polyzoa by Thompson (1830) and Bryozoa by Ehrenberg (1833). As a consequence, the same group of animals were attributed two names, Polyzoa and Bryozoa. Most of the American workers prefer to use the name Bryozoa and most English authors use the name Polyzoa. Nitsche (1869) divided Bryozoa into Endoprocta and Ectoprocta. But Hatschek in 1888 gave these two groups the status of separate phyla. Brien and Papyn (1954) gave supporting evidences to separate these two phyla.

AFFINITIES

Like Phoronids and Brachiopods, the systematic position of the Ectoprocts is also controversial. The controversy lies due to their structural alliances with other groups of animals.

Relationship with Phoronida

Caldwell (1888) emphasised the relationship between Phoronida and Ectoprocta. This idea was based on the presence of the following similar features. (1) The nerve centre is located in the mesocoel and is supraenteric. (2) Both are provided with horseshoe-shaped lophophore. (3) Presence of epistome. (4) U-shaped alimentary canal. (5) Similar disposition of the coelom and the presence of a septum separating the mesocoel and metacoel. But detailed study of the two groups showed many structural differences between them. They differ widely in their anatomical construction. The embryological development show many differences. The most important differences are: (1) The origin of coelom is different. (2) The region between the mouth and anus is dorsal in Phoronida and ventral in Ectoprocta. (3) Circulatory system and nephridia are absent in Ectoprocta, but in Phoronida both the systems are present. Because of these differences, the relationship between Ectoprocta and Phoronida cannot be established. Of the three lophophorate coelomates, the Phoronida is nearer to the lophophorate ancestor and the Ectoprocta occupies a subsequent stage.

Relationship with Brachiopoda

The Ectoprocta is related to Brachiopoda and possesses many common characters. The similar features are: (1) Both have similar body construction. (2) Bivalved shell of *Cyphonautes* larva of Ectoprocta is comparable to the shell of Brachiopoda. (3) Presence of a coelomic septum between the mesocoel and metacoel. (4) U-shaped alimentary canal. But due to the following structural differences, the relationship becomes very difficult to establish. The main differences are: (1) The nervous system is mainly supraenteric in Ectoprocta, but in Brachiopoda it is subenteric. (2) The brachiopod shell cannot be compared to the exoskeleton of Ectoprocta. (3) The shell is laterally placed in Ectoprocta, but in Brachiopoda the shell is dorso-ventrally placed. (4) The chitinous setae are present in Brachiopoda, but absent in Ectoprocta. Because of lack of specific relationship between them, the Ectoprocta and Brachiopoda are placed in two separate phyla having remote phylogenetic connections.

Relationship with Endoprocta

Many authors, specially Nitsche (1869) placed the Ectoprocta and Endoprocta as two classes under the phylum Bryozoa or Polyzoa, because of the presence of looped alimentary canal, ciliated tentacular circlet and the similarity in the larval stages. But a thorough examination reveals

that the two groups are fundamentally different. They exhibit the following differences: (1) The Ectoprocta possesses true coelom, whereas in Endoprocta true coelom is wanting. (2) The tentacular crown surrounds only the mouth in Ectoprocta, but in Endoprocta both the mouth and anus are enclosed by the crown of tentacles. (3) The nephridia and gonoducts are absent in Ectoprocta, but in Endoprocta both of them are present.

Considering these features, it is quite apparent that the Ectoprocta is highly organised than the Endoprocta and their exclusion as separate phylum is more reasonable. The similarities in the alimentary system are due to adaptive convergence and the larval similarities are common for all pelagic free-swimming larval forms.

From the relationship of Ectoprocta with other animals it is convenient to place the ectoprocts under a separate phylum having phylogenetic relationship with the other two lophophorate coelomates—Phoronida and Brachiopoda. As regards the intraphylar relationship between different groups of the phylum, the phylactolaemates are regarded to be very primitive ectoprocts because of the presence of (1) Cylindrical zooids, (2) Division of the body into epistome (protosome), lophophoral region (mesosome) and trunk (metasome), (3) Horseshoe-shaped lophophore and (4) Lack of polymorphism.

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This list for further reading includes only a few of the numerous publications in the field of Zoology. We acknowledge that the facts and figures used in the present book are largely based on these work. We feel that by consulting these books and reprints our readers will be much benefited.

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